2000

The use of on-line control: A developmental perspective.

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THE USE OF ON-LINE CONTROL: A DEVELOPMENTAL PERSPECTIVE

by

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A Thesis
Submitted to the College of Graduate Studies and Research
through Human Kinetics
in Partial Fulfilment of the Requirements for
the Degree of Master of Human Kinetics at the
University of Windsor

Windsor, Ontario, Canada

2000

0-612-52607-0

ABSTRACT

To date little research has addressed the abilities of young participants to respond to a change in visual information provided during movement execution. The present study attempted to determine the ability of 45 participants (5,7,9 years) to respond to a change in visual information during a discrete rapid aiming movement. A perturbation paradigm, where the target size changed after movement onset was used. In the control context, movements were made to each target size (small, medium and large) with no perturbation. In contrast during the experimental context, the target always began as a medium target. Upon movement initiation the target size could remain constant or might unexpectedly become larger or smaller. Temporal, kinematic and correction data was collected to determine the control process underlying the aiming movement.

No interaction was found between age and condition for movement time and results indicated that all ages scaled movement time to final target size. The accuracy data revealed that the nine year old participants were more accurate than the five and seven year old participants. To determine where the changes in duration were made, the time to and after peak velocity (TTPV, TAPV) , and peak velocity values (PV) were examined. The TTPV, and PV values indicated that during the control context the participants scaled their movement to the target size. However, during the experimental context generally no significant differences were found in either measure suggesting a programmed response based on the original target size. This was supported by the correction data collected prior to peak velocity, lending further support to a programmed response. Following peak velocity it was found that differences in MT were as a result of the time spent in deceleration. This increased TAPV and increased number of corrections observed suggest that all participants were using on-line control following peak velocity in response to the change in visual information.

The data collected supports a model of control that incorporates both open ioop control during the initial impulse phase, and closed loop control during the current control phase for participants as young as five years.

DEDICATION

In memory of Michael John Farrell.
He lives on in the sound of laughter and will never be forgotten.

ACKNOWLEDGEMENTS

The challenge of acknowledging everyone who stood by me in the preparation of this work has proven to be one of the most daunting tasks I have faced through this entire process. There are so many people who deserve my thanks.

I need to thank my advisor, Dr. Patti Weir. Without her this research would never have been possible. Her knowledge, insights and continued interest in learning have been inspirational. She continually amazed me with her patience, and understanding. We survived without a single voice being raised, even when I truly deserved a harsh word. She is too kind. Dr. Weir knows better than anyone the difficulty I often encounter when I try to put my thoughts on paper so hopefully, it is adequate when I simply say... thankyou.

I would like to express my gratitude to my committee members; Dr. Eric Roy, Dr. Bob Orr, and Dr. Marliesse Kimmerle. It has been an exciting ride, to say the least. It has been my very real pleasure to come to know each of you better over the past year, and I sincerely appreciate your counsel and advice. The rigours of science are difficult to swallow some days... but each of your suggestions contributed to this work... and I am very proud of it. Thankyou.

I would be remiss if I did not take the time to thank the staff and students of Notre Dame Separate School in Windsor, particularly the grade 2 teacher Beth Trottier. Beth, your help in recruiting the students was crucial for my research, thank you for your help in getting this party started. Without the staff, students, and parents of Notre Dame there would have been no party. Each student was a joy to work with and the teachers were always understanding of the continual interruptions to their daily routine. I appreciate everyone who made my time at Notre Dame such a pleasure.

I read somewhere that "friends are the family that you choose for yourself". Georgia, Maureen, Hilary, and Amanda, you are my family away from home. Each of you deserve a standing ovation for enduring my short temper and anxiety attacks as I worked my way through all of this. I appreciate your support and recognize your patience over the year, I am very fortunate to have such incredible friends.

Finally, my family. You have given me many gifts over the years not the least of which were your infallible love and support. Whenever I needed a kind word or push to continue, I knew I could count on each of you. As a family we have put behind us another year filled with both celebration and tragedy, and somehow managed to come out stronger. Each one of you has dealt with situations far greater than anything I have ever accomplished. You are my inspiration and have all of my love and respect.

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Each day during our daily actions we encounter countless situations where we reach out to contact another surface. The ability to contact another surface such as, dialing a phone, using a keyboard, or inserting a key into a lock requires visual perception of the target location and the subsequent translation into a motor act. Many of these actions require precise control on the part of the individual and are often refined during childhood. Williams (1983) reports that visual acuity, " the capacity of the visual system to detect or perceive detail clearly (p.114)" undergoes developmental changes. This has been defined as occurring between the ages 5-7, with a plateau between 7-9 years, and an improvement again at nine years of age. Surprisingly, little research has been performed to date regarding the abilities and performance of young children while engaged in a manual aiming movement. The data presented by Williams offers no indication as to the effect of the visual system on functional movements. The research that does exist is primarily concerned with the motor control aspect of movement and presents equivocal data as to the control processes underlying these movements in children (Hay, 1979; Chicoine, Lassonde, & Proteau, 1992; Charvin & Proteau, 1996). The work by Hay (1979) used only one source of feedback, while the work of Chicoine, Lassonde, & Proteau (1992) and Charvin & Proteau used multiple sources of afferent information to determine the control process abilities of the participants.

This research was developed in an attempt to contribute to the understanding of how children control manual aiming movements. To answer this question a comprehensive analysis was completed, with each piece of data providing a unique window into the locus of control being used during the movement. Analyses were completed on the participants movement patterns, kinematics and performance data. The goal of this study was to determine through the use of a target perturbation paradigm, at what age participants are able to use on-line visual feedback to help control their aiming movement. The precise control of a variety of movements is a seasoned question in the motor control literature.

The belief that movements are preprogrammed exists within a framework that suggests movement is an execution of pre-structured commands, commonly referred to as a motor program. These pre-structured commands are thought to be a program based upon the initial conditions and goal of the action. This is also known as open loop control (Schmidt, 1991). It is within this type of control system that movement is performed in the absence of feedback. An open loop control system has no mechanism with which to evaluate environmental feedback during movement execution (Adams, 1971). At the core of the programming theory is the belief that a response is determined entirely in advance of movement onset, and that the movement pattern generated is indicative of the original environmental parameters. Thus, if new information is available after movement initiation, it can not be incorporated because the open loop control system lacks a mechanism to do this. For example, in a perturbation aiming paradigm, if the target size is perturbed after movement initiation the new information that may modify the commands is not acknowledged by the system, and the movement is carried out according to the original target parameters.

In contrast, closed loop control systems, also referred to as on-line control, are thought to work in conjunction with feedback from the environment to evaluate the incoming visual information. This information is compared to the goal reference point and if a discrepancy exists between the two points movement modifications may be made to ensure accuracy. Closed loop theory postulates that these modifications occur on-line during movement execution and subsequently impact the kinematics of the movement (Adams, 1971). In a target perturbation situation participants should be able to use the new visual information to modify the original movement parameters. Thus, the movement executed should reflect the new target information and not the original target parameters.

In manual aiming the ideas of open loop control and closed loop control was first addressed in the pioneering work of Woodworth (1899) who coined the phrases "initial impulse" and "current control" as a means of describing two separate phases observed during adult manual movements. The initial impulse phase was responsible for the transportation of the limb towards the target, while during the current control, or homing-in phase, corrections required to ensure target accuracy were completed. The first phase was considered to be open loop in nature while, the second phase is dependent upon feedback from the environment indicating whether the movement will fall within the target boundaries. The terms open loop control and initial impulse will be used synonymously, as will closed loop, and current control to describe separate phases of the movement.

Fitts' seminal work in (1954) made the next large impact on the understanding of rapid aiming movements. Fitts' Law (1954) is a robust finding and has wide ranging applications that span from a laboratory pegboard task (Annet, Golby, & Kay, 1958) to underwater aiming (Kerr,1973) to foot pedal design (Drury, 1975). Fitts originally had participants perform a reciprocal tapping task which led to the development of a logarithmic relationship between movement time (MT) and index of difficulty (ID), where $MT = a + b \log_2 (ID)$. The index of difficulty (ID) is determined through the ratio of amplitude (A) and target width (W), such that 2A/W is indicative of the index of difficulty. Using this ratio, ID can be increased by decreasing target width, or increasing movement amplitude. With respect to the current study, Fitts' Law can be used as a means to uncover the control system being used. In a target perturbation paradigm where the size of the targets unexpectedly become larger or smaller the ID of the task changes, and the effects on the subsequent movement parameters can be observed. Given that the time associated with a movement is linearly related to the amount of information to be processed it follows that if the participant recognizes the change in ID during the perturbation trial it should be evidenced as a change in MT. However, these expectations are only relevant if the movement is controlled through a closed loop process in which the new information provided about target size, and ID, is incorporated into the system. If movements are controlled in an open loop fashion the movement time should reflect the original target ID.

Much of the developmental work on aiming movements have used Fitts' paradigm as their basis and have employed both serial and discrete tapping tasks, to determine the aiming abilities of children as young as five years to point both quickly and accurately to a target (Connolly, Brown, & Bassett, 1968; Hay, 1981; Kerr, 1975; Sugden 1980; Schellekens, Kalverboer & Scholten, 1984). It has been reported that as children age their movement times decrease which can be attributed to an increase in movement velocity, or a shortened homing in phase (Hauert, Zanone, & Mounoud, 1990 ;

Schellerkens,Kalverboer & Scholten,1984). These studies were also interested in determining the response processing capacity of the participants and it was reported that generally the participants were better able to handle the demands of the task as their processing capacity increased with age.

Movement time data alone does not provide a complete understanding of the movement abilities of an individual. As a result the movement patterns generated are often of interest in a manual aiming task. Mackenzie, Marteniuk, Dugas, Liske, & Eickmeier (1987) recorded a discrete aiming movement using an optoelectric system that monitored the actual position of the limb as it moved through space. These behavioural kinematic measures allow a more detailed spatio-temporal analysis of performance than can be gathered through temporal measures alone. Velocity profiles can reflect programmed versus on-line control. On-line control may be evident based upon the presence of corrections found in the velocity profile. Similarly, ballistic movement patterns characterised by an increased time before peak velocity may help to indicate programmed, or open loop control. The research by Mackenzie et al. (1987) revealed that adult aiming movements generally result in a bell-shaped velocity profile. This mature pattern is characterized by a smooth acceleration and deceleration. The acceleration portion (time prior to peak velocity) reflects Woodworth's initial impulse phase, believed to be preprogrammed; while the deceleration portion (time after peak velocity) reflects concurrent control, or that part of the movement that is dependant on visually based feedback.

While adults tend to exhibit stereotypic movement patterns, young children demonstrate less stable patterns. Current research that has focused on the movement patterns generated by children has found a variety of movement patterns observed across the age span of 5 to 11 years. This data suggests that with each unique pattern generated a different control mechanism may be underlying the production of the movement (Hay, 1979; Hay, Bard, Fleury, & Teasdale, 1991). Ballistic profiles support an open loop mode of control, a step profile provides evidence to support immature use of closed loop control, and mature pattern indicating an adult manner of using feedback to control the movement in a closed loop mode of control.

The control mechanisms and movement patterns utilized by children have been researched through two distinct methods. The first method has focused on non-monotonic changes observed in performance with an attempt to understand the basis for the performance differences. These non-monotonic changes refer to a decrement in performance accuracy at 7 years of age, which had been preceded by relatively accurate performance at 5 years, and followed again by an accurate performance at 9 years of age. Extensive developmental work describing these non-monotonic changes in spatial accuracy in aiming is available (Bard, Hay, & Fleury, 1990; Hay, Bard, & Fleury, 1986; Hay, 1979; Hay et al., 1991; Pryde & Roy, 1997). It is important to note that these non-monotonic changes in performance are only observed when vision of the limb and hand or cursor is deprived from the participant. Hay (1979), in part one of a two part research study, observed these changes in participants aged 5, 7, 9 and 11 years. The aiming task consisted of a horizontal movement of the extended arm toward a target with vision of the limb and hand occluded. The participants looked through a mask which maintained the head in a stable position while limiting their range of vision. The subjects had their extended arm placed in a metal cradle with a ball joint at the shoulder to allow horizontal movements. An abutment was placed to the right of the subjects limiting the movements on the right side. The abutment was the starting position for all aiming movements. Three targets spaced 20 degrees apart were adjusted so that they could be reached with the index finger of the extended arm. The device allowed the subjects to make horizontal pointing movements to the target indicated by the instructor. The use of on-line visual feedback was prevented by a black screen hung just below the targets that occluded the vision of the arm and hand from the participants. This placed the individual in an open loop situation as they could not adjust their movement based on any visual information that may have been provided on the way to the target. The participants were asked to move as accurately as possible, to the target without stopping and return to the starting position for the next trial. While accuracy was emphasized no importance was placed upon speed. Consistent with the theory of non-monotonic changes the 7 year old participants had poorer accuracy than those 5 years of age.

A second interesting finding that emerged was that the kinematic profile, or movement patterns generated changed as a function of age. A *ballistic movement pattern*, characterized by a single maximum velocity, with a sharp acceleration and deceleration, occurred most frequently at age 5 years and decreased rapidly with increasing age. The *mature pattern*, typically seen in adults, was characterized by a single velocity peak with a smooth acceleration and deceleration (Figure 1). Although this pattern was present at age 5 years it increased in frequency between 5 and 9 years. ***The step/ramp pattern*** was characterized by a low velocity with several sub peaks with no one peak clearly defined as the only, or the greatest peak (Figure 2). This pattern was rare at 5 years but increased in frequency at 7 years and remained at a similar level until 11 years of age. The discontinuous step/ramp pattern may indicate an individual's increased reliance on feedback and is represented by an increased number of velocity peaks derived while attempting to continually modify the movement.

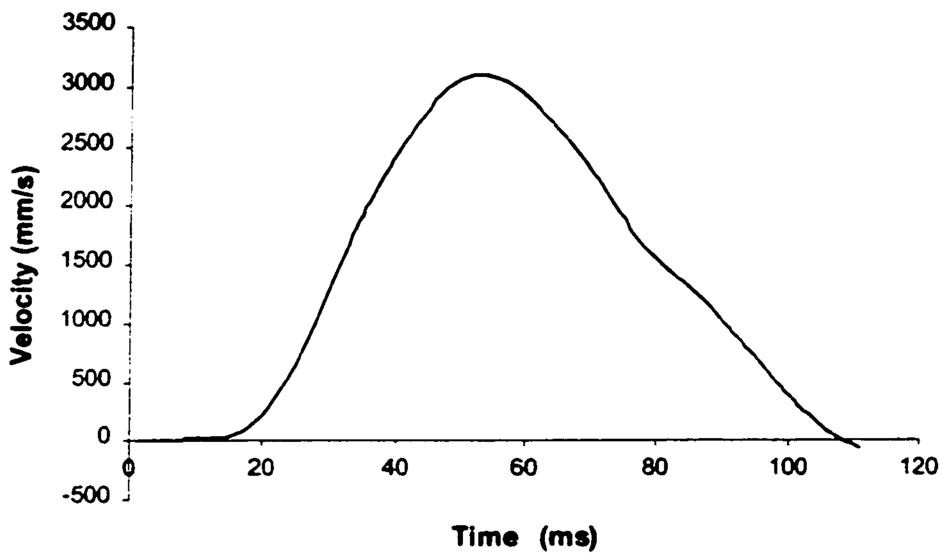

Figure 1. Representative mature velocity profile for a single trial for 1 participant age 9 years.

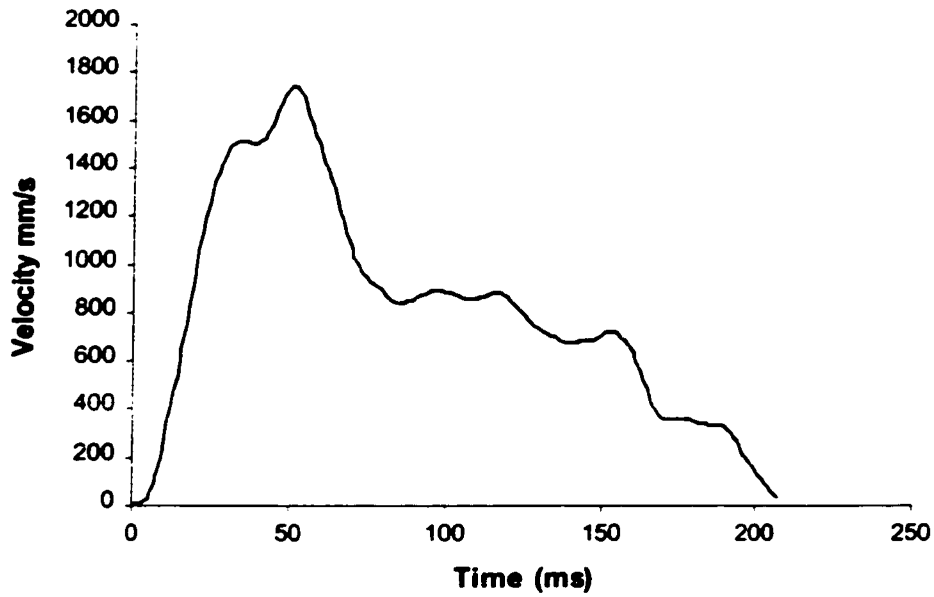

Figure 2. Representative step velocity profile for a single trial for 1 participant age 9 years.

These changes in movement patterns across the age span indicate a change in the control mechanisms underlying the movements. The frequency of ballistic patterns at age 5 years may indicate a reliance on a preprogrammed response, or open loop control with little regard for external feedback, although they were as accurate as the 11 year old participants. The 7 year old participants exhibited early braking activity which may indicate an increased reliance upon external cues to help guide the movement which leads to a decrement in performance. The 7 year old participants were less variable in their constant error but were also found to be less accurate than the 9 and 5 year old participants. The 11 year old participants appeared to be controlling the movement in a more efficient manner such that the use of feedback was restricted to the end of the movement to allow the ballistic phase of the movement to be carried out fully before the homing in phase was initiated. This restriction of feedback use until the end of the ballistic phase is characteristic of a mature movement pattern (Mackenzie et al., 1987). As a result this age group demonstrated an increase in accuracy and frequency of mature movement patterns The participants intra-individual variability decreased across the ages studied. While these patterns were observed only in the absence of vision of the hand and arm we might expect that when using a target perturbation some discontinuities may emerge in the velocity profiles if the participants were incorporating the new information on-line through the use of visual feedback. The major findings from Hay (1979) have been summarized and can be found in Table 1.

Table 1. Summary of results, Hay (1979).

	5 years	**7 years**	**9 & 11 years**
movement pattern	ballistic	step / ramp	mature
accuracy	accurate	not accurate	accurate
variability	variable	less variable	least variable
control mechanism	open loop	transition to closed loop	closed loop

More recently, Pryde & Roy (1997) had 48 children 7, 9 and 11 years of age perform a manual aiming movement in which the kinematics of the movement pattern were analyzed, along with reaction and movement time measures. The participants were expected to make quick and accurate movements to targets of various sizes and amplitudes, with and without visual feedback of a cursor. Movements were made along the midline with a computer mouse on a digitizing tablet to targets 1.25 cm or 2.25 cm in diameter at an amplitude of either 50 mm, 100 mm, or 150 mm. The participants were instructed to move to the target from the home position as quickly and accurately as possible. On those trials in which feedback was available to the participants the cursor position was visible at all times. On those trials in which feedback was not available vision of the cursor was removed 10 ms after target onset, (target onset was achieved through a button push controlled by the experimenter) and remained occluded for the remainder of the movement. It was determined that the changes in amplitude specification resulted in greater time spent in deceleration for the 7 and 9 year old participants in both the vision and no-vision conditions. It was also noted that the participants were less affected by the removal of vision as they aged. When vision of the cursor was permitted the majority of the movement patterns were of the mature type, the non-monotonic trends in spatial accuracy were not observed, greater peak velocities were achieved and less time was spent reaching peak velocity.

The second method of research examining control mechanisms, which more closely resembles the proposed research, involves the use of changing visual information in an effort to observe the effects on the movement performance. Hay (1979) attempted to determine the relative contributions of a programming system and a guidance system in the control of an aiming movement in participants 5,7,9, and 11 years of age. This second work was performed with children reaching with their entire arm, and included a visual perturbation. The participants were required to wear glasses in which a displacement prism could be put on the glasses without the child's knowledge. The participants were required to perform pointing movements towards a target located at an amplitude determined by the length of the participants arm. Each participant was able to touch the target with their index finger when their arm was fully extended. The participants were instructed to reach out and touch an illuminated red light in order to turn it off and return to the starting position to await the next trial. A series of movements were performed without the displacing prisms, then the prisms were placed on the glasses, and the trials continued. The prisms served to displace the target 17 degrees to the right. While wearing the prisms the participants would initially move towards the virtual target to the right of the actual target. Once the subjects hand came into the field of vision during movement execution the participants were able to estimate the trajectory error and correct the movement accordingly. The movements were filmed and analyzed to determine, first, at what moment the participant realized the discrepancy between the actual and virtual target, and second, when they corrected the movement based on the new visual information. Hay (1979) found that 5 year old children appeared to use a ballistic movement strategy indicated by the completion of the movement (100%) before the discrepancy was realized. This would seem to indicate the use of an open loop control process. That is, the subjects programmed their movement to the original target presented and did not use the visual feedback provided by the hand to modify the movement to ensure accuracy. This is in direct contrast to the 7 year old children who were observed correcting the trajectory when only 75% of the movement had been completed. These corrections earliest in the movement to accommodate the new information, suggests a reliance on visual feedback information to control the aiming movement. It can therefore be suggested they were operating within a closed loop mode of control. A different pattern again emerged for the 9 and 11 year old children who were able to correct the movement based on the new information without interrupting the ballistic or acceleration phase of the movement. These children were able to limit their corrections to the guidance phase of the movement, at approximately 92% completion and appeared to be using a closed loop mode of control. These data suggest a developmental shift in the ability to use closed loop control, similar to that shown by Hay's (1979) experiment. The five year old participants appear to be operating within an open loop mode of control, while the seven year old participants rely very heavily upon feedback indicating a closed loop mode of control. The nine and eleven year old participants appear capable of utilizing the feedback available effectively with little disruption to the movement. More effective use of the information provided allows the oldest participants the ability to move in a fluid continuous manner to the target.

This pattern of finding has also been reported for a coincident timing interception task. The gross motor interception task used by Williams (1973), involved catching a ball where the participants were asked to judge the speed and direction of a ball projected onto a canopy overhead by running to the place under the canopy where they felt the ball would land in time to catch the ball had the canopy not been there. It was revealed that all participants appeared to react to the flight of the ball equally fast that is, they began to move rather quickly upon sight of the moving object. With regards to accuracy and time spent moving it was found that the youngest movers appeared to move as far as possible in the time allotted, and as a result they were very inaccurate overshooting the interception position. This is similar to the ballistic movement findings of Hay (1979) and the long movement times reported in the developmental Fitts work (Connolly, Brown, & Bassett, 1968; Hay, 1981; Kerr, 1975; Sugden 1980; Schellekens, Kalverboer & Scholten, 1984). The children in the fourth grade (~ 9 years) were found to be more spatially accurate, but the speed in which they reached the target would have made the children too late to catch the ball successfully. Williams (1973) reports " ... the child is now able to use available visual information to guide his motor behaviour, the processing and translating of this visual input into motor behaviour still remains a slow operation (pp. 137-138)." These slow and accurate movements seem to indicate an inability to smoothly coordinate the visual and motor systems together for a quick and accurate movement that would allow the participant to be successful. Perhaps the subjects recognized where they "should" be, but were simply unable to move their body to the appropriate place in the time required. The ten year old participants were found to be accurate as well as quick to the position where the ball would have landed. This would appear to indicate a better coordination between the visual and motor system allowing the participant to be accurate and on time. Although the ages associated with the successful interception of a moving ball in a gross motor situation do not fit exactly with the ages associated with the aiming movements, the patterns observed appear to be similar for both tasks with the youngest movers (~ 5-7 years) being highly inaccurate with longer movement times moving towards a successful integration of both speed and accuracy for the oldest movers (~ 9-10 years). The low task demands associated with an aiming task may account for the shift being observed at a lower age level (7 years), and a higher age level (9 years) for the more complex gross motor task.

A more natural way to examine the use of on-line visual feedback has recently been developed by Heath, Hodges, Chua & Elliot (1998). The task still employs the use of a visual perturbation, but now the perturbation involves the physical parameters of a target in an aiming task. Adult participants completed aiming movements on a graphics tablet to a target displayed at a fixed amplitude on a computer screen. The aim of the study was to determine the ability of the participants to utilize new visual information provided after movement onset to modify the previously planned aiming movement. The participants were asked to complete a series of control trials to targets defined as small, medium and large that always remained the same size. During the experimental trials the target was always originally presented as a medium size, however, during 24% of the trials the target would unexpectedly change in size to either smaller or larger after movement onset. If the participant preprogrammed the movement entirely in advance the perturbation of the target size, and subsequent change in the ID (Fitts 1954) would have no effect on the movement kinematics, or the movement time. Accordingly, if the participant possessed the ability to modify the movement on the way to the target (on-line) it would be evidenced by a change in movement time associated with those trials in which a perturbation occurred. The control and experimental trials support Fitts Law such that movement time increased as target size decreased . This indicates that the young adults were able to incorporate new visual information on-line and modify their movements during the later stages based on the new information provided during the experimental trials (Heath et al., 1998).

To examine the performance changes at the older end of the developmental continuum, Heath, Roy, & Weir (1999) attempted to compare the response of older adults (67.25 years) to those of younger adults (19.85 years) on the same visual perturbation aiming task again; in support of the earlier work, it was found that during the experimental trials the younger adults were able to modify their movements on-line, operating in a closed loop mode of control, thereby allowing the new spatial-temporal constraints to be met. This was in contrast to the older adults who did not change their movement patterns in response to the new target constraints imposed by the change in target size. Thus, the older adults appeared to be operating within an open loop mode of control.

The work by Heath et al., (1999) indicates that young adults were able to program rapid aiming movements on-line, while it seems that this is not true of older adults who did not modify their movement based upon the new information provided and appear to be operating in an open loop mode of control. While Hay (1979) has shown that there is a shift in the use of closed loop control with increasing age it is unclear how this ability would emerge in children when responding to a visual perturbation that occurs after movement initiation. Therefore, using a target perturbation paradigm similar to that of Heath et al. (1998) the current study was performed to determine at what age the ability to reprogram a rapid movement on-line emerges in children.

The purpose of this research was to determine the mode of control used by children performing a manual aiming movement with a target perturbation. This research was unique in that it was the first developmental study to couple kinematic, performance, and movement correction data. This combination of measures allowed a comprehensive evaluation of open and closed loop theories as they pertain to children.

Predictions:

It was hypothesized that:

1. during the control condition a linear increase would be seen in movement time as the target size decreased. This is consistent with the work of Fitts (1954) in which it was shown that as the index of difficulty increased the movement time also increased.
2. as the target size decreased the time spent after peak velocity would also increase. This has been found previously by Mackenzie et al. (1987).
3. during the experimental condition slower movement times would be expected when moving to the large targets and faster times when moving to the small target when compared with the corresponding control condition. This would be consistent with the findings of Heath et al. (1998) in which they found that subjects were able to modify their movements on the way to the target but were unable to reach the same velocities as in the control condition.
4. based on the findings of Heath et al. (1998) and Heath et al. (1999) it was hypothesized that no difference would be found in the experimental condition, for all age groups

with regard to peak velocity reached when moving to any of the target sizes. This is based on the belief that peak velocity is programmed prior to movement initiation and would reflect the original medium target parameters regardless of the final target size.

5. the 5 year old participants would exhibit primarily ballistic movement patterns with fewer mature movement patterns, while the 7 year old participants were expected to display a greater number of step movement patterns, and the nine year old participants were expected to show more mature movement patterns. This would be consistent with the frequency of movement pattern findings of Hay (1979).
6. the 5 year old group would have poor accuracy scores, while the seven year old group was expected to have the most accurate scores. This hypothesis is based on the belief that the 7 year old group relies heavily upon feedback to help guide the movement as found in Hay (1979), and Pryde & Roy (1997).
7. as a result of the perturbation, 7 & 9 year old participants would be observed making a number of corrections while moving to the target to allow their movement to be spatially accurate. It was expected that the seven year old participants would have the greatest number of corrections based upon their reported reliance on feedback (Hay 1979; Pryde & Roy 1997).
8. based on the above predictions and data presented by Hay (1979) and Pryde & Roy (1997) it was predicted that the five year old participants would be operating within open loop control, with the seven and nine year old participants within closed loop control.

Methodology

Participants

Forty-five students from Notre Dame Separate School in Windsor, Ontario participated in the study. There were 15 senior kindergarten students, 15 grade two students, and 15 grade four students (Table 2). Permission was obtained from the Windsor - Essex Catholic District School Board and the principal of Notre Dame Separate School. The participants were nominated by their classroom teachers based on the inclusion/exclusion criteria found in Pryde & Roy (1997):

1. Appears to be of average, or above average, intelligence;
2. Is not known to have academic or behavioral difficulties (e.g. Learning Disorder, Attention Deficit Disorder);
3. Does not demonstrate difficulty with motor tasks (e.g. handwriting, craft activities, gym activities, tying shoelaces)
4. Is not known to have uncorrected vision or hearing problems.

Parental permission was obtained for each student through their classroom teacher. The parent/guardian was asked to complete a consent form, and help their child complete a questionnaire. The child's questionnaire entitled ~ Computers and Me ~ was designed by Pryde and Roy (1997) (Appendix A). It was developed to determine the computer and mouse experience of each participant. The results of the questionnaires were analysed using a 1 way between groups ANOVA. The results indicated that no significant differences existed between the age groups with regards to previous computer experience,.$F(2,42) = 1.06$, $p>.05$ A copy of the instructions to the teachers can be found in Appendix B, while the parental consent form can be found in Appendix C.

Table 2: Subject Characteristics

	5	**7**	**9**
Age	5.58 years	7.50 years	9.58
Gender	7M / 8F	8M / 7F	8M / 7F
Computers & Me (12)	mean score 10.13	mean score 10.6	mean score 11.0

Apparatus and Task

An illustration of the apparatus used can been seen in Figure 3. A wooden box (630 mm X 650 mm X 575 mm) was divided by a fully silvered mirror. The mirror was mounted at a 15 degree angle, with the anterior edge of the mirror at a height of 175 mm. from the table surface. A hole was cut in the upper surface of the box corresponding to the monitor dimensions to allow the monitor to be placed in a fully inverted position. The mirror allowed for a direct mapping situation such that the targets appeared on the surface of the mirror in the same plane as the movements would be made on the graphics tablet. The cursor and targets were then projected onto the surface of the mirror. A Summa Sketch III graphics tablet sampled at 122.3 Hz (temporal resolution = 8.17 ms per frame) and was situated directly beneath the mirror inside the box. Participants performed the aiming movements on the tablet with a computer mouse. There was a one to one proportional correspondence between the cursor movement on the mirror and the mouse movements made on the graphics tablet.[1] Once the cursor was placed in the home position a target (5mm, 12mm, 31 mm) in diameter appeared 150 mm directly anterior to the home position. A mouse support was designed to ensure a consistent starting position for each subject and trial.

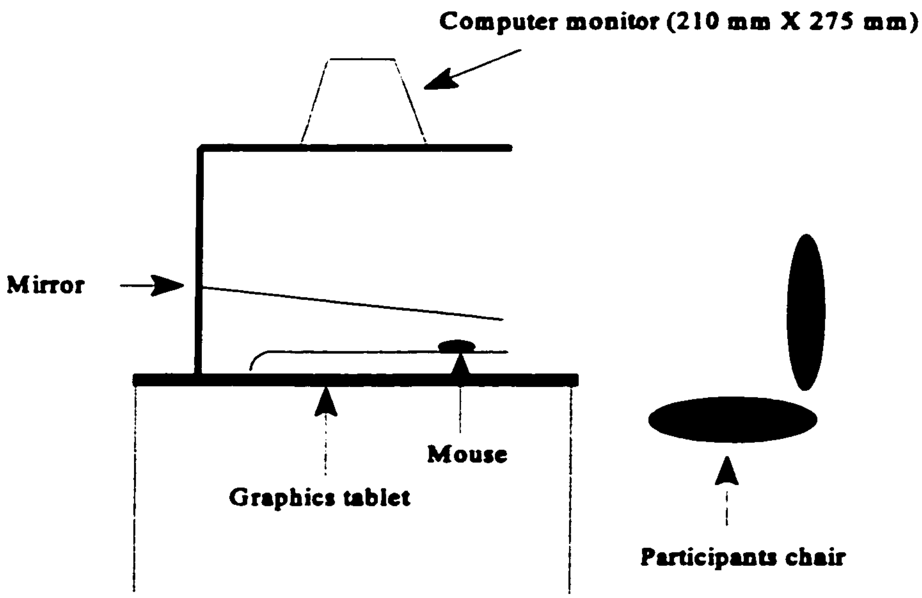

Figure 3. Schematic representation of experimental apparatus.

Procedure

The participants were seated in front of the target aiming apparatus with the midline of their body aligned to the primary direction of the movement. Once the cursor was situated in the home position the trial began with the appearance of a target.[2] The participants were instructed to move the mouse from the home position to any position within the target boundaries as quickly as possible. Vision of the home position, target and cursor was available throughout all of the trials. For all trials the participants moved the solid yellow cursor from the home position to the target as quickly as possible and pressed the mouse button to signal the end of the movement. In the experimental trials a solid red medium size target of 12 mm appeared anterior to the participant at an amplitude of 15 mm. The amplitude of the movement was held constant across all trials. During 76% of the trials the target size remained constant at 12 mm, with a corresponding ID of 4.6 bits . However, during the remaining 24 % of trials the target perturbed to become larger 12% of the time (31 mm, ID of 3.3 bits), and smaller 12% of the time (5 mm, ID of 5.9 bits).[3] In these perturbation trials the size change occurred when the mouse had been moved 10 mm from the start position in the y-direction (anterior - posterior), the primary direction of movement. In the control trials the target appeared at an amplitude of 150 mm. The target size presented was dependent upon the randomized order for each subject and corresponded to the perturbed diameters found in the experimental situation (5, 12, 31 mm). In the control situation the target appeared and remained a constant size for the duration of the trial.

Each participant completed 10 practice trials consisting of 6 medium targets and four perturbation trials, with two perturbations to a larger target and two perturbations to a smaller target. Accordingly, the participants were aware that the target could change size during the experimental trials. All subjects appeared able to handle the task requirements and required no extra practice sessions.

Due to the concern of limited attention and motivation of the young participants testing was held on two separate days with the order of trial presentation shown in Table 3. Following the completion of the 10 practice trials on day one the participants were asked to complete 9 randomized control trials. The participants were then asked to complete 50 randomized experimental trials, followed by another 9 control trials. This completed the testing requirements for day one. On day two, following the ten practice trials the participant was asked to complete the remaining 18 control trials, 9 before the experimental trials and 9 following the experimental trials. The control trials consisted of 12 movements to each of the target widths, with no perturbations. The trial presentation during the control and experimental trials was randomized for each participant.

Table 3. Summary of testing sessions.

Trial Type	Day One	Day Two
Practice	10 total...6 med, 2 sm,2 large	10 total...6 med, 2 sm, 2 large
Control	9 total... randomized	9 total... randomized
Experimental	50 total...38 med, 6 sm, 6 large	50 total... 38 med, 6 sm, 6 large
Control	9 total... randomized	9 total... randomized
Total # of trials	78	78

Data Reduction

The raw data obtained from all trials was filtered using a second order dual pass Butterworth filter. The cutoff frequency of the low pass filter of 6 hz was used. This was determined through a residual analysis as outlined in Winter (1991). Instantaneous velocity, in the primary direction of movement (y-axis) was obtained by differentiating the displacement data using a three point central finite algorithm. Instantaneous acceleration was calculated by differentiating the velocity data using the same algorithm. The beginning of the movement was defined as the point in time when the instantaneous velocity was equal to or greater than 5.0 mm/sec and remained at or above this criterion for at least 72 ms (9 frames). The end of the movement was defined as the point in which the instantaneous velocity fell below 5.0 mm/sec, and remained at or below this criterion for at least a period of 72 ms (9 frames). Movement time (MT) was calculated by determining the number of frames between the defined start and end of the movement and multiplying by 8.17 ms. Peak velocity (PV) is the highest point on the velocity profile, and occurs at the point of zero acceleration. Time to peak velocity (TTPV) was determined by identifying the frame in which peak velocity was reached and subtracting this value from the frame defined as the start of the movement, and multiplying by 8.17 ms. Time after peak velocity (TAPV) was simply the difference between total movement time and time to peak velocity (Figure 4).

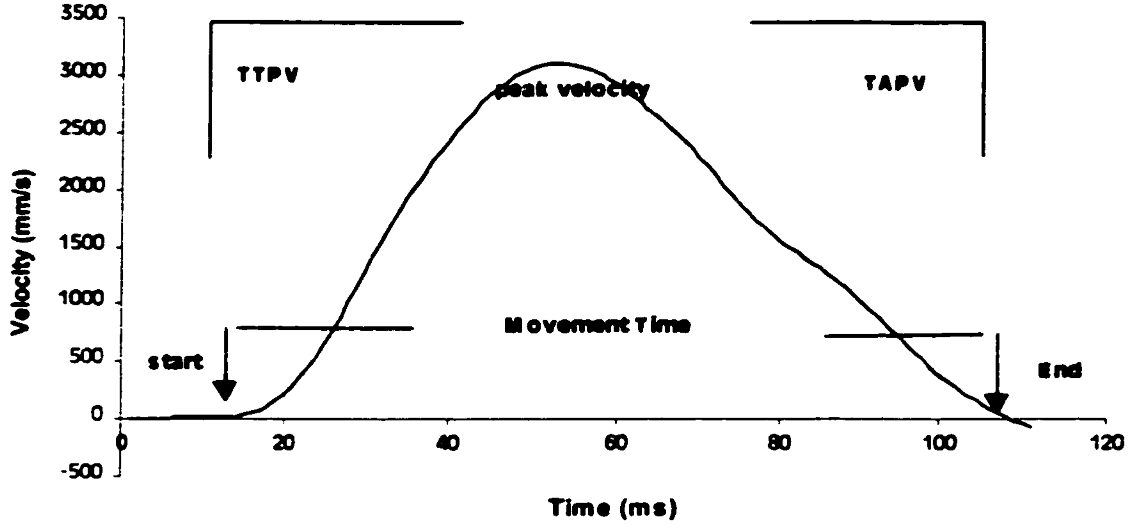

Figure 4. Representative velocity profile outlining the kinematic dependent variables.

Data Analysis

In an effort to determine whether modifications to the movement trajectory occurred an analysis of the acceleration profile was completed. Corrections were observed on the acceleration profiles and included deviations before and after peak velocity. Deviations are defined as reversal points other than peak acceleration and peak negative acceleration (Brooks, 1974). The deviations were considered both prior to and after peak velocity and must have met two criteria. First, the reversal must have lasted at least 72 ms (9 frames) and second, the reversal must have had an amplitude of at least 10% of the greatest absolute magnitude in acceleration (Chua & Elliott, 1993). This temporal criterion was chosen as it has been shown that secondary movement corrections take at least 70 ms to complete (Van Donkelaar & Franks, 1991). Significant deviations on the acceleration profile are thought to reflect a continuous mode of control, one where the corrections made to a movement do not prompt a change in the sign of the acceleration trace (Figure 5)

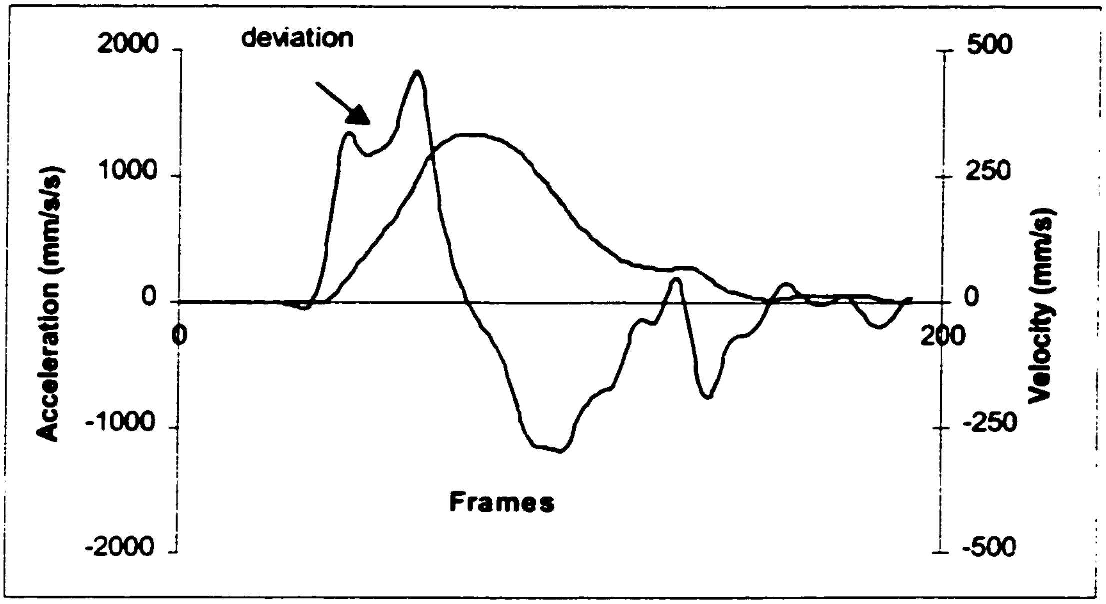

Figure 5. Representative sample of a significant deviation superimposed over an mature movement pattern.

The dependent measures included movement time, peak velocity, time to peak velocity, time after peak velocity, number of corrections (deviations) before and after peak velocity, constant error, variable error, and absolute constant error. Constant error was defined as the mean signed error between the center of the target and the cursor position at the end of the movement in the y-axis, while variable error is the within - subject standard deviation of the signed errors. Absolute constant error was defined as the absolute value of the constant error for each condition for each participant. These error measurements were calculated to determine if the spatial accuracy and consistency of the participants was affected by the experimental manipulation. The dependent variables were calculated on a trial by trial basis and a mean was obtained for each subject for each condition. Lastly, a frequency count was calculated for each velocity profile as per the movement pattern criteria outlined by Hay (1979). This was done to determine if form changes with age.

Statistical Analysis

Consistent with the findings of Hay (1979), and Pryde &Roy (1997) the participants exhibited three distinct types of movement patterns: *ballistic*, consisting of rapid acceleration and deceleration with only one peak velocity, *step*, consisting of gradual acceleration and deceleration with more than one velocity peak, and *mature,* consisting of a gradual acceleration and deceleration with only one velocity peak. Due to the varied movement patterns exhibited by the participants several dependent measures such as time to peak velocity, time after peak velocity and all corrections made before and after peak velocity rely on the accurate determination of the peak velocity. This value can only be identified with confidence in the mature movement patterns, therefore, only the mature movement patterns exhibited by each of the participants were analyzed. This is consistent with the data analysis criterion used by Pryde and Roy (1997). Analysis of the frequency of mature patterns exhibited did not reveal an age main effect, $F(2,42) = 1.16$, $p>.05$. The full analysis can be found in Appendix D.

Table 4 contains the percentage of trials that were excluded due to a failure to fulfil the start/end criteria and the percentage of trials that were of the mature, step, and ballistic movement pattern type.

Table 4. Characteristics of trials collected.

	5 yrs	**7yrs**	**9yrs**
trials excluded	9.3%	7.1%	0.80%
mature	68.3%	72.8%	76.0%
step	22.4%	19.9%	23.2%
ballistic	0.0%	00.20%	0.0%
Total	100.0%	100.0%	100.0%

To determine the effect of the two testing sessions held on different days movement time was analyzed with testing day as a variable. This analysis revealed no significant effect for day, $F(1,40) = 2.83$, $p > .05$. As a result all data was collapsed across day and all dependent variable means were analyzed using a 2 Condition (control, experimental) X 3 Target (3.3 bits, 4.6 bits, 5.9 bits) X 3 Age (5yr, 7yr, 9yr) mixed ANOVA with repeated measures on condition and target. The statistical software package Statistica 5.1 was used to analyze the mean data. Significant effects involving more than two means were further analyzed using a Tukey's HSD procedure. Statistical significance was evaluated using $p<.05$.

Results

Table 5. Significant age main effects for each dependent variable.

	5	7	9
Movement Time (ms)	1024.36	905.96	1072.50
Peak Velocity (mm/sec)	335.61	418.89	335.08
Time After PV (ms)	685.86	610.16	736.09
Constant Error (mm)	-1.20	0.84	-0.65
|Constant Error| (mm)	4.52	4.07	3.27

Table 6. Significant condition x target interactions for each dependent variable.

	Control			Experimental		
	s	m	l	s	m	l
Movement Time (ms)	1100.08	997.93	910.87	1058.39	977.05	959.31
Peak Velocity (mm/sec)	343.07	365.85	376.56	360.59	370.27	362.84
Time To PV (ms)	344.56	318.61	318.95	320.93	315.96	321.68
Time After PV (ms)	754.49	679.32	592.40	737.46	663.03	637.53
|Constant Error| (mm)	3.33	3.33	5.41	3.75	3.58	4.35

Performance Measures

Analysis of mean movement time revealed a main effect for age, F (2, 42) = 5.02, $p<.05$, a main effect for target, F (2, 84) = 67.64, $p<.05$, and an interaction between condition and target, F (2, 84) = 7.82, $p<.05$. Movement time was found to be significantly shorter for the 7 year old group when compared to the 9 year old group and the 5 year old participants (Table 5). Movements made to the three target sizes during the control condition were found to be consistent with Fitts Law (1954), that is, as index of difficulty increased a linear increase was also observed for movement time. During the experimental condition it was revealed that movements made to the small target were significantly longer in duration than those made to the medium or large target, also consistent with Fitts (1954).

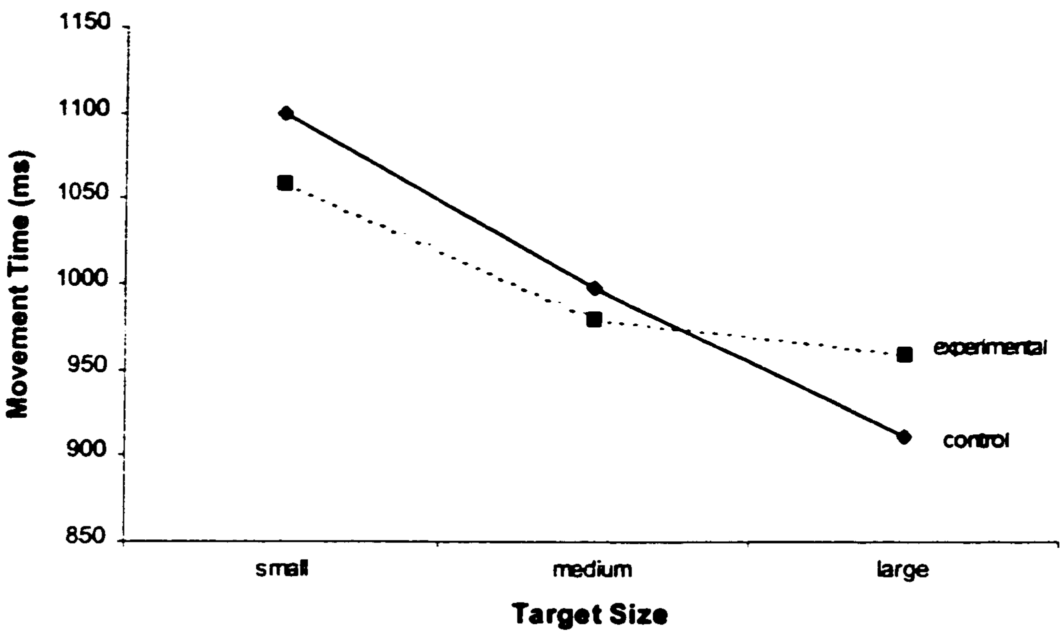

Figure 6. The effects of condition as a function of target size on movement time.

Analysis of constant error revealed a main effect for age, F (2, 42) = 7.33, p<.05, and a main effect for condition, F (1, 42) = 4.79, p<.05. Further analysis of the accuracy data revealed that the 5 year old participants were significantly less accurate than the 7 year old participants. Both the 5 and 9 year old participants were found to undershoot the target while the 7 year old participants overshot the target. The participants were found to be less accurate when moving in the control condition (-0.62 mm) compared to the experimental condition (0.06 mm).

No significant effects were found for variable error. Variable error is believed to be a measure of consistency in performance. This would seem to indicate that regardless of the target size or experimental manipulation all subjects performed in a consistent manner from trial to trial.

Analysis of absolute constant error revealed a main effect for age, $\underline{F}$ (2, 42) = 5.69, $\underline{p}$<.05, a main effect for target, F (2, 84) = 22.23, p<.05, and an interaction between condition and target, F (2, 84) = 6.37, p<.05. Measures of absolute error indicate a measure of accuracy without regard for the sign of the error value. It was revealed that the 5 and 7 year old groups were less accurate than the 9 year old group. Closer inspection of the effect of target size indicates that as target size decreased the accuracy increased. These data coupled with the movement time data are supportive of a speed accuracy tradeoff. It would appear that subjects sacrificed the speed of their response to ensure accuracy. As well, during the control condition, as the target size increased the error also increased. The boundaries of the large target allow for greater dispersion from the center, while still being within the confines of the target dimensions. No significant differences were found among the target sizes during the experimental condition.

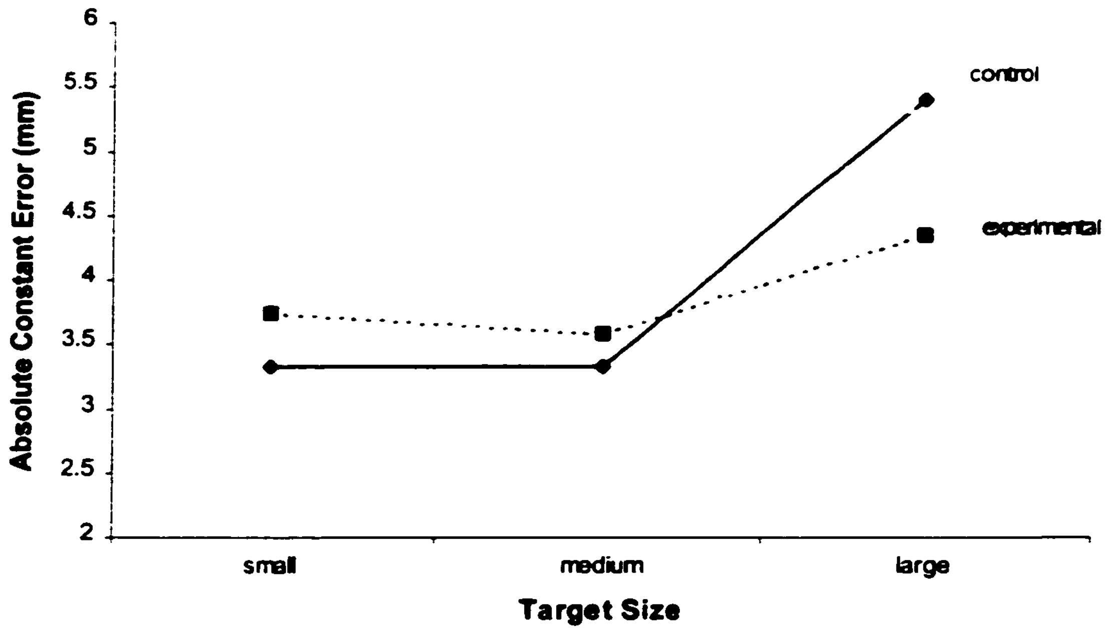

Figure 7. The effects of condition as a function of target size on absolute constant error.

Kinematic Measures

Analysis of peak velocity revealed a main effect for age, F (2, 42) = 5.98, $p<.05$, and a main effect for target, F (2, 84) = 9.06, $p<.05$. Significant interactions were found for condition and target, F (2, 84) = 5.53, $p<.05$, and age, condition and target, F (4, 84) = 2.83, $p<.05$. The age main effect revealed that the 7 year old participants were found to program higher peak velocity values than both the 5 and 9 year old participants (Table 5). This is consistent with the shorter movement times of the 7 year old subjects. A simple effects analysis was used to decompose the 3- way interaction. Age X Target mixed ANOVA's were run for both the control and experimental conditions. For the control condition an age main effect, $F(2,42) = 5.04$, $p<.05$, and a target main effect, $F(2,84) = 9.85$, $p<.05$ were revealed. The age main effect indicated that the 7 year old participants programmed larger peak velocities than the 5 and 9 year old participants who did not differ. The target main effect revealed that larger peak velocities were programmed to the medium and large targets, than to the small target. These data indicate that participants as young as 5 years of age are capable of scaling their peak velocity value to the target size presented and possess the ability to program a motor response. Analysis of the experimental condition revealed an age main effect, $F(2,42) = 6.70$, $p<.05$, and a significant interaction between age and target, $F(2,84) = 3.56$, $p<.05$. The age main effect again indicated that the 7 year old participants programmed larger peak velocity values than the 5 and 9 year old participants who did not differ in peak velocity. The interaction indicated that the 7 and 9 year old participants did not differ in the peak velocity value programmed regardless of final target size. In contrast, the 5 year old participants programmed a lower PV to the small target only, with no difference between the medium and large targets. These data are partially consistent with the belief that peak velocity is programmed prior to movement initiation. The 7 and 9 year old participants revealed that regardless of the perturbed target size they programmed their peak velocity prior to movement initiation based on the presentation of the original medium target. The exception to this was the 5 year old participants who responded with a lower peak velocity to the small target in the experimental condition. The age x target interaction graphs for PV can be seen in Figures 8 and 9.

Table 7. Significant effects of age, condition, and target on peak velocity (mm/sec).

	AGE (Years)		
CONTROL	**5**	**7**	**9**
small	306.0	391.6	331.7
medium	340.2	410.2	347.1
large	350.5	440.8	338.3
EXPERIMENTAL			
small	322.75	430.3	328.7
medium	345.49	431.9	333.4
large	348.68	408.5	331.3

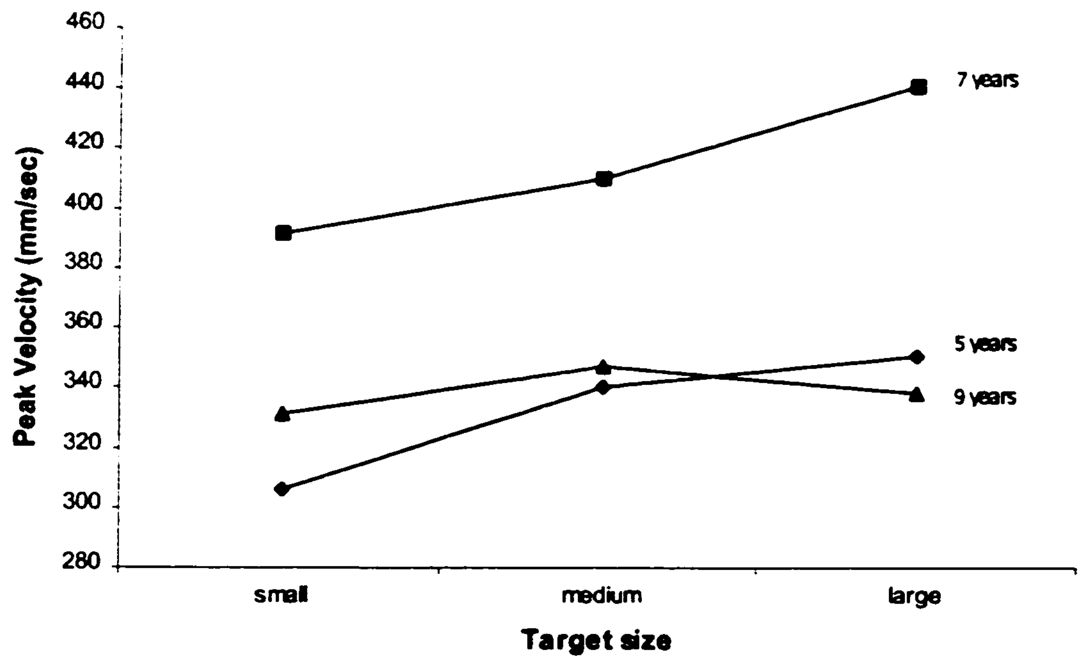

Figure 8. The effects of age as a function of target size for the control condition on peak velocity.

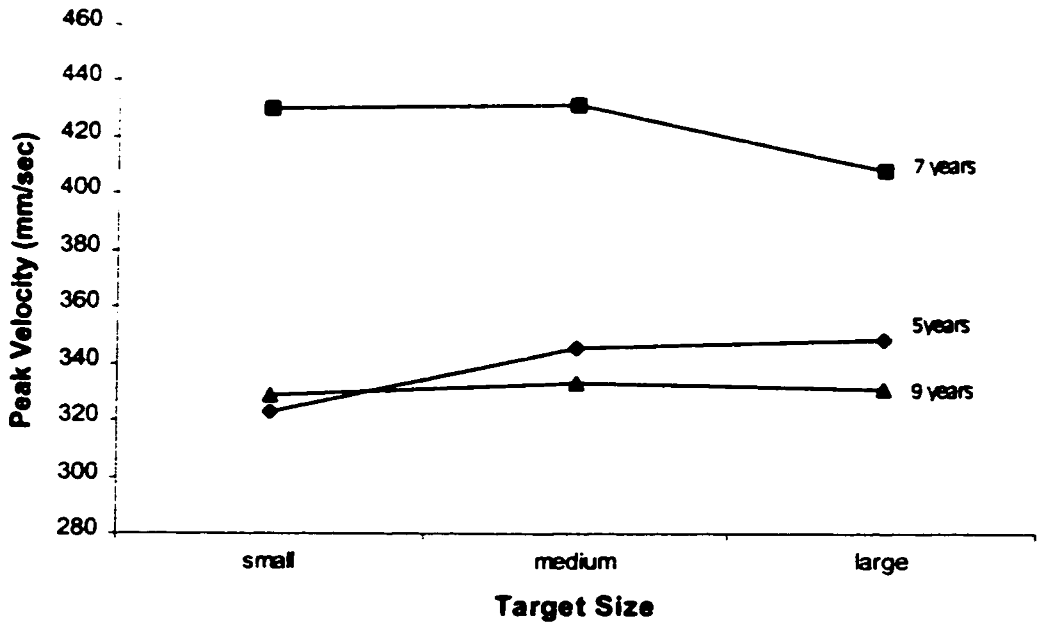

Figure 9. The effects of age as a function of target size for the control condition on peak velocity.

Analysis of time taken to reach peak velocity revealed a main effect for target F (2, 84) = 4.02, p<.05, and an interaction between condition and target, F (2, 84) = 3.42, p<.05. The interaction revealed that during the control situation the acceleration portion was lengthened to the small target as compared to the medium and large targets. In contrast, during the experimental condition no differences were found in the time taken to reach peak velocity. This is consistent with the peak velocity data and provides further support that the initial portion of the movement is programmed in advance.

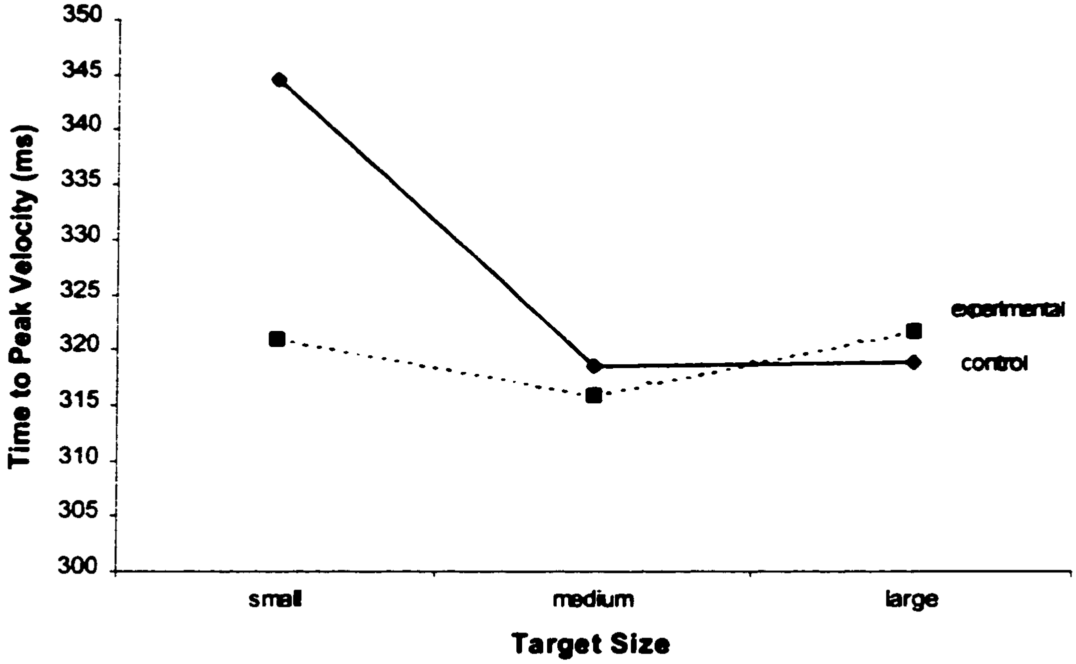

Figure 10. The effects of condition as a function of target size on time to peak velocity.

Analysis of time spent after peak velocity revealed a main effect for age, F (2, 42) = 5.42, $p<.05$, a main effect for target, F (2, 84) = 62.01, $p<.05$, and an interaction between condition and target, F (2, 84) = 5.65, $p<.05$. The main effect revealed that the 9 year old participants spent more time in deceleration than the 7 year old participants (Table 5). The interaction revealed that during the control condition the participants spent more time after peak velocity when moving to the small target than the medium or large targets. Significant differences existed between each of the target sizes. This is in contrast to the experimental condition in which more time was spent in deceleration when moving to the small target, while no differences were observed between the medium and large targets.

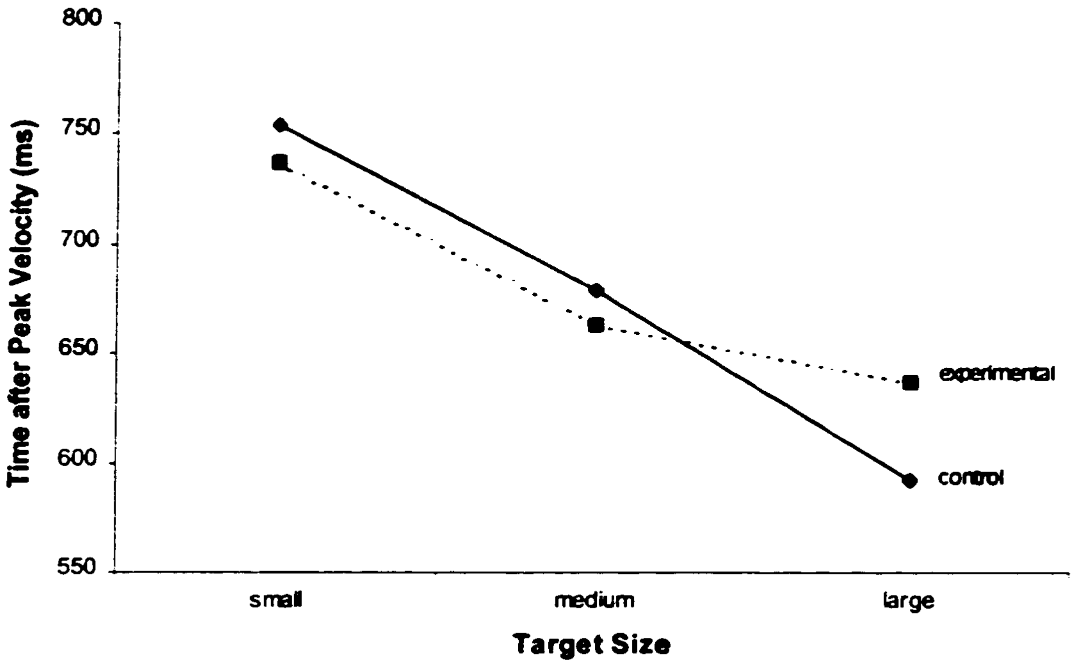

Figure 11. The effects of condition as a function of target size on time after peak velocity.

Movement Corrections

Deviations are believed to be secondary corrections to the movement indicating a continuous mode of control (Chua & Elliott, 1993). Analysis of deviations made prior to peak velocity revealed no significant main effects or interactions.

Analysis of deviations made after peak velocity revealed a main effect for age, $F(2, 42) = 5.42$, $p<.05$, and a main effect for target, $F(2, 84) = 3.47$, $p<.05$. The 9 year old participants were found to have a significantly greater number of deviations after peak velocity than the 7 year old participants. Consistent with the time spent in deceleration data more deviations were found when moving to the small target (1.2) than the large target (1.08).

The overall means reported for the deviations are quite small due to a large number of trials involving zero corrections. It was determined that percentages of trials involving 0, 1, 2, 3,4, and greater than 4 corrections would also be examined in an effort to determine the pattern of corrections used by the participants. The significant findings from this analysis will be discussed in detail. A complete description of the percent deviations before peak velocity and after peak velocity per condition and age can be found in Appendix E.

Analysis of the percent deviations made prior to peak velocity revealed a main effect for corrections, $F\ (5,210) = 166.40$, $p<.05$, and an interaction between age and corrections, $F\ (10,210) = 2.29$, $p<.05$. The interaction revealed that all participants had significantly more trials without any corrections than those trials with one, two, three, four or greater than four corrections, no differences were found when comparisons were made between trials containing two, three, four, and greater than four corrections. When the differences between age were analyzed it was revealed that the 7 year old participants had more trials without any corrections than the 5 and 9 year old participants who were not different from one another. The 9 year old participants had a greater number of trials with only one correction than the 5 and 7 year old participants who did not differ significantly.

There were no differences between the age groups on percentage of trials with 2, 3, 4, and greater than 4 corrections.

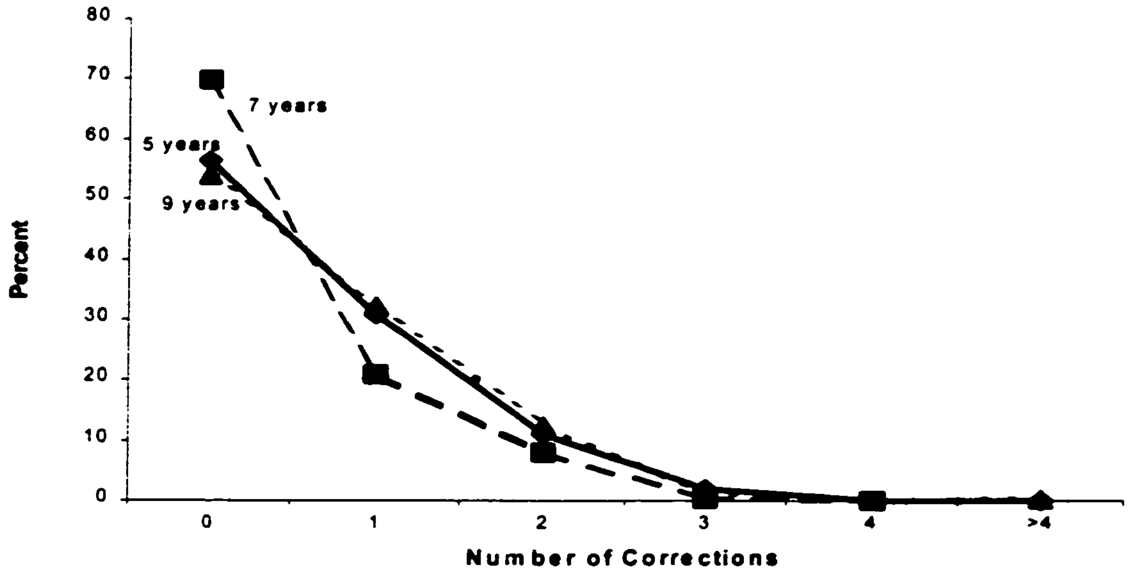

Figure 12. The effects of age and corrections expressed as a percent value prior to peak velocity.

Analysis of the percent deviations made after peak velocity revealed a main effect for corrections, $\underline{F}$ (5,210) = 118.4, $\underline{p}$<.05, and an interaction between age and correction, $\underline{F}$ (10,210) = 4.13, $\underline{p}$<.05. The interaction revealed that the 5 year old participants had significantly more trials with only one correction than those with zero, two three, four, or greater than four corrections. The 7 year old participants had no significant differences between the percentage of trials with zero or one corrections, while significant differences existed between the percentage of trials with one, two, or three. The 9 year old participants had no significant differences between the percentage of trials with zero or one correction. There were significant differences between the percentage of trials with one, two, and three corrections. The 7 year old participants had the greatest number of trials with zero corrections when compared to the 5 and 9 year old participants. No differences existed between the age groups when comparing percentage of trials with 2, 3, 4, or greater than 4 corrections. The age effect for these data is consistent with that for MT, and |CE| in which the 7 year old subjects moved the quickest with the greatest absolute error scores.

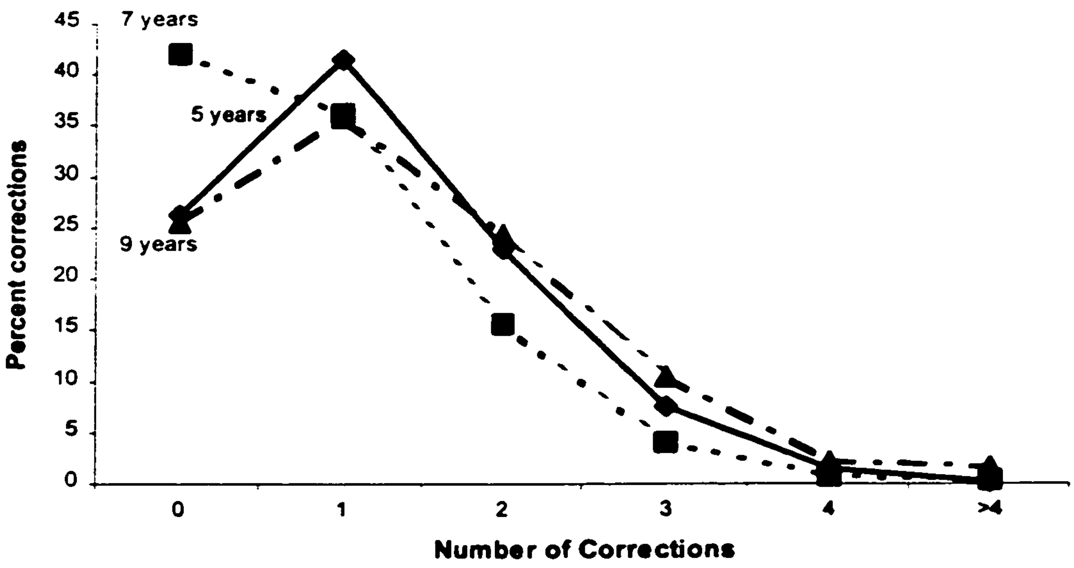

Figure 14. The effects of age and corrections expressed as a percent value post peak velocity.

Discussion:

The aim of the present study was to investigate developmental trends in manual aiming. This was achieved through a manual aiming task that involved the use of a perturbation paradigm to determine the on-line control abilities of each age group. The kinematic variables, performance measures, and movement patterns exhibited were of interest in an effort to clearly determine the mode of control underlying the movement. It was proposed that the movement may be under the influence of one of two different control mechanisms. The first being open loop control in which a movement is carried out independent of feedback based upon the original target information. The second, closed loop control in which visual feedback is used to help guide the movement accuracy. While these two means of control have been proposed to be independent of one another the present data lends support for a combination of both mechanisms controlling separate phases of the movement. This will be discussed in some detail as it relates to primarily the interaction findings. Prior to that an analysis of the developmental findings and their ramifications on the theoretical question of on-line control will be discussed.

In terms of the age related findings, it is important to note that although age was involved in a number of main effects which were summarized in Table 5, none of the other independent variables studied were differentially affected by age. A summary of findings similar to those presented for Hay (1979), Table 1, can be found below in Table 8.

Table 8. Summary of age related findings for present study.

	5	7	9
Movement pattern	mature	mature	mature
Speed	slow	fast	slow
|Constant Error|	not accurate	not accurate	accurate
Variability	not variable	not variable	not variable
Zero Corrections	fewer	most	fewer
Control Mechanism	closed loop	closed loop	closed loop

The movement patterns exhibited by the participants provide a window into the control mechanism underlying the control of the rapid aiming movement. This study was not unique in monitoring the movement patterns. Similar data has been collected previously by Hay (1979) and Pryde and Roy (1997). Consistent with the work of Pryde and Roy (1997) the present data reflects similar percentages of mature movement patterns performed by the participants. Pryde and Roy (1997) report that during the vision condition the participants exhibited greater than 90% mature movement patterns while during the no-vision condition they still reported greater than 75% mature patterns. While the participants involved in the present study performed only under full vision conditions it was also found that greater than 68% of all the trials for all age groups were of the mature type. This finding is in contrast to the findings of Hay (1979) who reported very few mature movement patterns at five years (~ 20%), seven years (~ 40%), and nine years (~ 30). Thus, the current data do not support hypothesis 5. These equivocal findings among the studies may be attributed to the vastly different tasks employed by the researchers. The similar findings between the present study and the findings of Pryde & Roy (1997) may be due to the fact that both utilized a target aiming study involving a computer mouse and a graphics tablet, whereas, the Hay (1979) study required the subjects to point to a target without vision of their arm in space. Thus the more controlled task environment resulted in more mature patterns.

MT was analysed and revealed only a main effect for age indicating all participants recognized the change in target size and subsequently altered their movement times accordingly, suggesting the presence of on-line control. The 7 year old participants were found to move the fastest. This is in contrast to hypothesis 8 in which it was stated that the 5 year old participants would not recognize the change in target size provided, and the seven year old participants would rely heavily upon the information. All participants were observed speeding up their movement to the large target and slowing down to the more spatially precise small target, presumably through use of visual information to guide the movement. These hypotheses for movement patterns and MT were based on the findings of Hay (1979) who reported that the five year old participants moved in a ballistic manner, while the seven year old participants were observed moving with a great deal of reliance on feedback to guide the movement. Unfortunately no movement time data was collected during the Hay (1979) trials. As a result, it is simply speculation that participants moving ballistically would have shorter movement times, whereas, those relying upon feedback would show longer movement times. The present data, supporting on-line control, were found to be more consistent with the findings of Charvin, & Proteau (1996), Chicoine, Lassonde, & Proteau (1992) where based upon their accuracy data collected during a transfer task they determined that their participants were also operating within a closed loop mode of control. The aiming task performed by the participants involved in the Proteau & colleagues (1992, 1996) studies involved multiple sources of afferent information (proprioceptive & visual). Their hypothesis was that children as young as 5 years would operate within a closed loop mode of control. Although the research differs in the manner in which on-line control was determined, (no perturbation) their design also incorporated a manual aiming task with a computer mouse and graphics tablet, similar to that used in the present study. Proteau & colleagues (1992, 1996) supported their hypothesis regarding the presence of closed loop control at the age of 5 years.

Considering that MT is simply the sum of the TTPV and the TAPV the effects of MT should exist within one of these two measures. Further analysis revealed no significant effect of age in the time leading up to peak velocity as shown through the absence of an age main effect or interaction. However, the MT findings are paralleled by the TAPV data in which an age main effect was also found. It mirrors the MT age main effect such that the 7 year old participants spent less time in deceleration than the 9 year old participants. Recall that the seven year old participants moved the most quickly and the nine year old participants more slowly. The 5 year old participants did not differ significantly from the 7 and nine year olds in their TAPV data. The 7 year old participants are moving more quickly to the target and do not appear to slow down to the same extent as the nine year old participants as they approach the target. Consistent with the temporal measures of MT and TTPV the PV data indicates that the 7 year old participants are programming higher peak velocity values than the 5 and 9 year old participants lending further support to the pattern of behaviour for age findings, in which they are moving more quickly than the 5 and 9 year old participants

Since the work of Woodworth (1899) it has been believed that "current control", or homing in on the target occurs following peak velocity and can be evidenced by not only the duration of the that portion of the movement but the presence of corrections as well. One of the fundamental lines of inquiry for this study relied on the correction data generated by each participant to determine whether the visual feedback provided was used, indicating on-line control.

It is believed that it is during the deceleration phase of the movement that subjects began their homing phase to ensure an accurate response. This was not supported by the present data in which it was found that the seven year old participants had the greatest number of trials without any corrections. Hypothesis 7 stated that post peak velocity the 7 year old participants would make the greatest number of corrections, again based upon the earlier findings regarding their increased reliance on feedback as reported by Hay (1979). This may not be surprising given that the seven year old participants were moving the fastest and did not slow as much following peak velocity, and as a result may not have had time to use the information to make corrections, thereby decreasing there end-point accuracy.

The terminal position of the movement is of interest in determining the effectiveness of the control mechanism underlying the movement. Absolute constant error was used to this end. The analysis revealed that the 5 and 7 year old participants were less accurate in their final position relative to the center of the target than the 9 year old participants. The 9 year old participants were found to be the most accurate. This is contrary to hypothesis 6 in which it was believed that the 7 year old participants would be the most accurate. The 7 year old participants involved in the Hay (1979), and Pryde & Roy (1997) study were found to be quite accurate in their movements. Hay (1979) attributed this accurate movement to an increased reliance on feedback to help guide the movement. In the present study this does not appear to be the case with the 7 year olds participants. The 9 year old participants in the present study were found to be the most accurate and the slowest movers.

The work of Woodworth (1899) has been instrumental in the line of research that has focused on aiming movements. He broke the movement down into two distinct phases "initial impulse" and "current control". It is believed that during the initial impulse that the limb is quickly transported towards the target while homing in or current control occurs as the limb approaches contact with the target. The data collected in the present study echo the findings of Woodworth (1899) and support a model of control that incorporates both open loop control during the initial impulse phase, and closed loop control during the current control phase.

The present movement time data supports the work of Fitts (1954), and hypothesis 1 in which it was expected that a change in MT would be expected when moving to the different target sizes during the control condition. Similar findings were also reported by Heath et al., (1998) & Heath et al., (1999). The experimental data revealed that all subjects responded to the change in target size with a change in MT, suggesting on-line control. However, they were unable to speed up or slow down the movement to similar velocities that had been reached in the control condition, consistent with the findings of Heath et al. (1998). This MT data was mirrored by the TAPV findings in which the interaction between target and condition revealed that the TAPV was affected by the final target size, with an increased time spent in deceleration when the target perturbed smaller, indicating the use of on-line control.

The correction data provides a complementary line of support for the use of on-line control following peak velocity. The correction data revealed that as the target size decreased the number of corrections required to ensure accuracy increased.

The temporal and kinematic data suggest that the time following peak velocity is controlled through a closed loop process, which is supported by Woodworth (1899), Heath et al. (1998), and Heath et al., (1999).

The question of what is taking place prior to peak velocity has not yet been addressed. This can be determined through the analysis of TTPV and PV. The TTPV data indicates a significant target by condition interaction mirrored by the PV data. During the control situation more time was spent in acceleration, with smaller PV values observed when moving to a small target than when moving to a medium or large target. This indicates that participants were capable of scaling their movement to the final target size and is evidenced in the PV value reached and the length of the acceleration portion of the movement. The present experimental data revealed no significant differences in the time taken to reach peak velocity. With the exception of the 5 year old participants moving to the small target, there were no differences in the magnitude of peak velocity reached in the experimental condition. These data are supportive of the work by Heath et al. (1998), and

Heath et al., (1999) in which it was also found that PV was not affected by changes in target size during the experimental trials. These data are consistent with hypothesis 4 based on the work of Heath, et al. (1998), and Heath et al. (1999). In these studies it has been shown that regardless of the change in visual information and despite a change in MT, indicating on-line control abilities, the participants did not alter their PV values, or time taken to reach peak velocity suggesting a programmed response based upon the original target size (medium) and indicative of open loop control

The correction data is consistent with the belief that open loop control processes are underlying the initial impulse phase. The target main effect indicating significantly more trials without any corrections prior to peak velocity lends further support to the belief that PV and those events leading up to peak velocity are programmed prior to movement initiation and are unaffected by the final target size.

The TTPV and PV data supported by the correction data confirms that the initial impulse of the movement is guided by open loop control, while the current control phase of the movement is controlled through closed loop control. These on-line control conclusions are based upon the temporal, performance and movement pattern data.

In conclusion, based on the data from the present research it has been found that all subjects are responding to the aiming task with closed loop abilities. The visual information provided was used to alter the movement execution after peak velocity which is evident in the MT, and TAPV data. The control data is consistent with the work of Fitts (1954): as task complexity changed the MT associated also changed accordingly. The experimental findings are consistent with the work of Heath et al. (1998) in which young adults were able to use the on-line visual feedback to help guide the movement. Further work in this area by Heath et al. (1999) failed to reveal on-line control abilities in older adults. The presence of age effects for older adults may be attributed to a conservative movement strategy in which they are concerned with an error free performance (Salthouse, 1985). It may also be as a result of a decrement in visual acuity and processing that does not allow the individual to alter the movement based on the visual feedback. An inability to find significant age effects in the present study indicates that all participants are capable of using the visual feedback to alter the movement time but does not translate into similar movement production across all ages.

The ability to use the visual feedback to help ensure accuracy does show some developmental differences. These differences may be a result of an information processing limitation in the five year old participants and a cognitive strategy shift between the seven and nine year old participants. Perhaps the 5 year old participants are unable to process the visual information provided by the change in target size into a meaningful motor response that allows their movement to be quick and accurate. The 7 year old data may indicate a strategic emphasis placed upon speed rather than accuracy, or it may also be the result of a speed of processing difficulty. In contrast, the 9 year old data suggests a strategic emphasis based on an accurate rather than a quick response.

The information taken in by the perceptual-motor system is of little value if the individual has no means by which to process this information in the time required. Information processing models have been proposed that attempt to diagram the processes required to perform a motor act. The information processing models generally indicate the components believed to be required in the learning and performance of a motor skill (Haywood,1986).

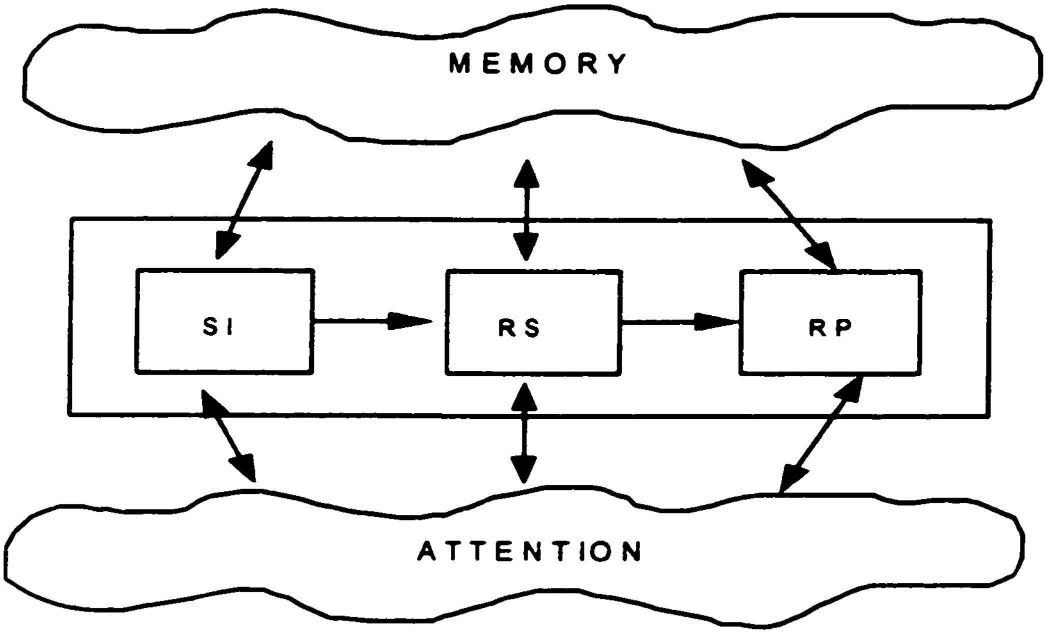

Figure 14. Schematic representation of the information processing model.

This approach to looking at the motor system assumes that there are discrete information processing stages, similar to a computer, that information (input) must pass through before a motor act (output) is performed. These stages include stimulus identification (SI), response selection (RS), and response programming (RP). Each of these stages are affected by memory and attention (Figure 15). This stage analysis of performance assumes that information enters as input and is processed by the first stage and then passed on to the second and third stages which results in an action at the output end of the model. Much of the research associated with the information processing model is derived from reaction time (RT) data. While no RT data was collected during the present study previous work by H & R (1960) and K&E (1976) describes a relationship between RT and MT in which an increase in RT has been associated with an increase in MT.

During the stimulus identification stage an analysis of the environment is undertaken, and the information received from the senses including visual, auditory, and kinesthetic is analysed and encoded. During the response selection stage, based upon the information received and encoded during the stimulus identification stage, a decision as to the movement to be carried out is determined. Finally, during the response programming stage the motor system is organized and activated based upon the environmental information. It is during the output stage of the model when the motor act is actually being carried out, that the use of on-line visual feedback would be observed. In relation to the current task, information received during the input stage was the visual target size, and the response selection was predetermined to be an aiming movement. During the response programming stage activation of the motor system occurs resulting in a movement towards the target. Specific to the model presented, during this aiming task memory plays a very minor role, while attentional demands play a large role if the participant is to be successful. Differences in programming may help explain some of the age related differences . While it is a common observation that movements made by children are slower than those performed by adults there is no simple answer for these developmental differences. Several researchers have identified different processes within the information processing model in which children show a decrease in performance.

Smith, Kemler, & Aronfried (1975) found that young participants (5 & 6 years) attended to both relevant and irrelevant task information when presented in a perceptual display lending support for the belief that selective filtering and attention may play a role in the decrement in performance observed for young children. While, Clark (1982) observed longer processing times for the children involved in a two choice reaction time task. When the stimulus response pairings were incompatible the delays observed were attributed to the response selection stage. Chi (1977) found that children were slower at initial information retrieval and encoding when attempting to name familiar and unfamiliar faces, and believes that speed of encoding was the central factor that explained the differences observed across the age span. Regardless of the process or processes involved, motor performance is intricately linked to: 1) an individuals ability to move information through the system quickly in response to the environmental cues and, 2) the ability to make appropriate adjustments (Thomas, 1980).

Changes in the information processing abilities of the participants seem best able to answer the change in performance between the ages of 5 and 7 years, while between 7 and 9 years represents a cognitive strategy shift. The 5 year old participants, in this study were observed to move slowly and were inaccurate in their responses, while the 7 year old participants were found to move quickly and also inaccurately. This is consistent with the work of Brewer & Smith (1989) in which they found their 5 year old participants, and to a lesser extent the 7 year old participants to be inconsistent in their accuracy monitoring.

Their 5 year old participants were also characterized by very slow and overly cautious responses, similar to the present findings, with adjustments that indicated poor control over speed. In contrast the 7 year old participants had better developed speed control. These results have recently been corroborated by Miller & Vernon (1997), who also support that slower processing speed in young children is a function of less accurate response monitoring. Most importantly, Miller & Vernon (1997) concluded that the rate of change in processing speed is faster in young children with a declining rate of change with increasing age. This is consistent with the current data in which it was found that MT decreased with increasing age, but only up until 7 years. If information processing deficiencies were to explain the developmental findings across the entire age span it would be expected that the 9 year old participants would have had faster, not slower movement times than the 7 year old participants. Thus, it appears that the 9 year old participants may not be the victim of information processing delays, rather they may be experiencing a strategy shift.

It is proposed that based upon the MT and accuracy data the 9 year old participants were in fact utilizing a cognitive strategy during the response programming stage that placed more emphasis upon an accurate rather than a speeded response. The nine year old participants in the current study were found to be moving slowly but were the most accurate in their responses. Brown, Sepehr, Ettlinger, & Sreczek (1986) also reported that their 9 year old participants while moving in partial and full vision conditions produced responses that were analogous with a speed accuracy tradeoff. That is, the participants placed a greater emphasis upon an accurate response and sacrificed speed to ensure accuracy as evidenced by their longer movement times.

These speed accuracy data coupled with the correction data support Thomas' (1980) view of the complex relationship between age, speed of response and the closed loop control system. While providing a theoretical explanation of the current data the delineation between speed of processing and strategy shifts requires further exploration before definitive conclusions can be drawn.

A complimentary explanation to the one provided could also be used to lend further insight into the data reported. The constraints theory was hypothesized by Roy, Weir, & Leavitt (1996) to explain performance differences observed between younger and older adults in manual tasks. The model suggests that both "hardware" (neuroanatomical) and "software" (strategies) may play a role in the observed differences. The hardware and software changes might be dependent on the constraints of the task (sensory, physical, high level) (Mackenzie & Iberall, 1994). The constraints theory may also lend an insight into the pattern of findings of the present research. The suggested information processing changes across the age span of 5 - 7 years is not unlike the hardware explanation of Roy et al. (1996) in which it is believed that the neuroanatomical limitations and sensory constraints (developing neural pathways) affect the participant's performance. In contrast, a "software" explanation may account for the performance changes between 7 - 9 years. Software changes are believed to be a result of high level constraints which require subjects to adopt different strategies to complete the task. In the present study 9 year old participants adopted a strategy of accuracy over speed. Thus, while the two explanations, information processing and constraints theory, rely on different premises their interpretations are complimentary for the current data.

In conclusion, the current study has advanced our understanding of the control mechanisms underlying the production of an aimed movement, and more specifically it has provided a comprehensive analysis of the age related changes in aiming performance. This is the first known study to examine the corrective actions used by children and the data suggest developmental changes are occurring in the information processing system.

Future research should attempt to determine the cognitive strategies that are used by the children. Changes in the instructional set delivered to participants of each age would artificially place the individual in a situation where they must place an emphasis upon speed or accuracy separately, thereby controlling the strategy used. Further analysis in this research area, particularly developmental work that may rely upon information processing model should record the reaction time (RT) data associated with each movement, as most literature related to information processing utilizes RT measures. As a result of the task constraints the initial stages proposed in the information processing model are probably not affected by the change in target size. The current data suggested that all participants recognized the change in target size but performed differently. To determine what is occurring and where in the planning process further research needs to be completed. To determine if the assumptions, as they relate to the information processing model are correct it would be necessary to systematically evaluate the stages of information processing. Additionally, by fractionating the RT it would allow an examination of the central versus peripheral (motor) factors involved in movement production. A three part study could be undertaken requiring recognition, movement initiation, and movement completion. Initially, participants could be asked to indicate at what moment they observed the target size change, without requiring a motor response. Next, the participant could be asked to initiate a movement and indicate when they observed a change in target size. Finally, the participant could be asked to complete the movement to the target following the change in target size. Through the change in instructional set the task would be altered from a recognition task to a task requiring a completed motor response. If the analysis resulted in no age effect for the recognition task or movement initiation task it could be inferred that central processing factors did not differ between the age groups studied. Furthermore, if performance differences were observed for the task requiring movement completion it could be hypothesized that the differences were a result of peripheral or motor factors required for movement execution. Future developmental work should continue to bridge the gap between descriptive research and the impact upon functional movements in children.

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Footnote

1. The observed movement on the mirror is 60% of the actual movement on the graphics tablet. The 15 cm movement on the tablet is observed to be a 9 cm movement on the mirror. A one to one proportional correspondence exists such that when 10% of the movement is completed on the tablet 10 % is also observed to be completed on the mirror.

2. Target sizes reported are based on values determined through measurement of the target widths on the computer monitor, while the amplitude was verified using the x, y coordinates on the graphics tablet.

3. The subjects have 5 seconds between trials to place the cursor back into the home position. In an effort to aid this task a holder for the mouse such that the cursor is close to the position.

Appendix A

~Computers and Me~
(Pryde & Roy, 1997)

~ Computers and Me ~

1. Have you ever used a computer before? YES NO

2. Do you have a computer at home? YES NO

3. Do you use a computer at school? YES NO

4. Do you like to work on the computer? YES NO

5. How often do you use the computer?

ALL THE TIME	ONCE IN A WHILE	HARDLY EVER	NEVER
(almost every day)	(once a week)	(once a month)	

6. Have you ever used the mouse on a computer? YES NO

7. How often do you use the mouse?

ALL THE TIME ONCE IN A WHILE HARDLY EVER NEVER

8. What have you used the mouse for?

PLAYING GAMES DRAWING

9. Do you like using the mouse? YES NO

Appendix B

Parental Consent Form

UNIVERSITY OF
WINDSOR

January 4, 2000

Information Letter

Dear Parent,

This study is concerned with the ability of children to recognize a change in visual information while performing an aiming movement. This study is being conducted by Ms. Sandra McKay, and supervised by Dr. Patricia Weir from the Kinesiology Department.

Each child will be asked to perform a series of aiming movements. This task requires the use of a computer mouse to move a cursor from a home position to a target displayed on the computer screen. On some trials the target size will remain constant throughout the trial, while on others the target will become larger or smaller upon movement initiation. The child's goal on each trial is to move the cursor to the target location.

Due to the length of the testing procedure the children will be asked to participate in two separate sessions. Each session is expected to last approximately fifteen minutes.

There are no anticipated risks associated with participation in this study. All data collected will be used for research publication purposes. The child's anonymity is guaranteed, and consent to participate, or the use of the data collected may be withdrawn at any time.

In an effort to determine the amount of experience the child has with a computer mouse a questionnaire entitled Computers and Me has been provided. If, after reading the consent form you are interested in having your child participate please sign the attached consent form and help your child complete the questionnaire entitled Computers and Me. Please return by Wednesday March 3, 1999 to your child's teacher.

This project has received ethical clearance from the Graduate Committee of the Department of Kinesiology at the University of Windsor. Any comments about the study or your child's participation may be directed to Dr. R. Boucher, (519) 253-3000, ext. 2429.

I understand if I have any questions about this study I may contact Sandra McKay at the University of Windsor (519) 253-3000, ext. 2429, or her supervisor, Dr. Patricia Weir at (519) 253-3000, ext. 2443.

Thank You,

Sandra M. McKay, B.H.K.

KINESIOLOGY
SCHOOL OF HUMAN KINETICS
401 SUNSET . WINDSOR ONTARIO . CANADA N9B 3P4 . 519 / 253-4232
FAX 519 / 973-7056

Parental Consent Form

University of Windsor
School of Human Kinetics

I.., the parent/guardian of

.... have read the outline of the study to be conducted by Sandra M. Mckay, University of Windsor. I agree to my child's participation in the study with the understanding that:

1. My child can withdraw from the study at any time.

2. My child's identity will remain confidential.

3. This study has been approved by and received ethics clearance through the Graduate Committee of the Department of Kinesiology. Dr. R. Boucher (ext. 2429) is available to receive any comments or concerns with regard to my child's participation in this study.

I understand if I have any questions about this study I may contact Sandra Mckay at the University of Windsor (519) 253-3000, ext. 2429, or her supervisor, Dr. Patricia Weir at (519) 253-3000, ext. 2443.

____

(Signature of parent or guardian)

____

(Date)

Appendix C

Instructions to Classroom Teachers

UNIVERSITY OF
WINDSOR

January 4, 2000

Dear Teacher,

Thank you very much for your interest in participating in my research project. Your participation is very much appreciated as this study will contribute to our understanding of the developmental progression of the control processes underlying rapid aiming movements.

I would like to ask for your assistance in selecting a minimum of 15 children from your class to participate in this study. I have enclosed Information Letters and Parental Consent Forms that you may send home with the children you select. Please consider the following criteria when making your selection:

The child:

1. Appears to be of average, or above average intelligence;

2. Is not known to have academic or behavioural difficulties (e.g. Learning Disorder, Attention Deficit Disorder);

3. Does not demonstrate difficulty with motor tasks (e.g. handwriting, craft activities, gym activities, tying shoelaces)

4. Is not known to have uncorrected vision or hearing problems.

I have requested that the consent forms be returned to you by Wednesday March 3, 1999. I will contact you on Thursday the 4th to arrange to pick-up the consent forms, and we can begin to schedule testing sessions in late January. Every effort will be made to ensure that the testing session disrupt your normal classroom routine as little as possible.

Thank you for your time and effort in selecting these children. If you have any questions or concerns please feel free to call me at 253-3000, ext. 2429, or my advisor Dr. Patricia Weir at 253-3000, ext. 2443. I look forward to meeting with early in the New Year and wish you the happiest of holiday seasons.

Yours truly,

Sandra M. McKay, B.H.K.

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Appendix D

Mature Movement Patterns: Frequency of Occurrence

Summary of all Effects; design: (goodtrials.sta)
1-VAR1, 2-COND, 3-TARGET

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	2	0.144998	42	0.124773	1.162101	0.322683
2	1	0.206631	42	0.037015	5.582355	0.02285
3	2	0.29186	84	0.019199	15.20174	2.32E-06
12	2	0.029669	42	0.037015	0.801545	0.455378
13	4	0.04936	84	0.019199	2.570957	0.04366
23	2	0.003959	84	0.013898	0.284867	0.752838
123	4	0.01669	84	0.013898	1.200925	0.31654

age
Means (goodtrials.sta)
F(2,42)=1.16; p<.3227

	Depend. Var.1
5 years	0.683674
7 years	0.728119
9 years	0.763791

cond
Means (unweighted) (goodtrials.sta)
F(1,42)=5.58; p<.0228

	Depend. Var.1
control	0.697531
exp	0.752859

target
Means (unweighted) (goodtrials.sta)
Rao R (2,41)=17.00; p<.0000

	Depend. Var.1
small	0.785185
medium	0.671881
large	0.718518

agexcond
Means (goodtrials.sta)
F(2,42)=.80; p<.4554

	Depend. Var.1
5c	0.668519
5e	0.69883
7c	0.67963
7e	0.776608
9c	0.744444
9e	0.783138

agextarget
Means (goodtrials.sta)
Rao R (4,82)=4.02; p<.0050

	Depend. Var.1
5s	0.763889
5m	0.589912
5l	0.697222
7s	0.797222
7m	0.706579
7l	0.680556
9s	0.794444
9m	0.719152
9l	0.777778

TUKEY -posthoc

$3.31 * \sqrt{0.019/30}$

value = 0.083

targetxcond
Means (unweighted) (goodtrials.st
Rao R (2,41)=.24; p<.7912

	Depend. Var.1
cs	0.764815
cm	0.642593
cl	0.685185
es	0.805556
em	0.70117
el	0.751852

Appendix E

Three-way Interaction Tables

Movement Time

	5 years			7 years			9 years		
	s	m	l	s	m	l	s	m	l
Control	1120.1	1027.4	935.5	1015.3	904.4	807.5	1164.9	1061.9	989.7
Experimental	1091.7	997.3	974.3	938.6	882.0	887.9	1144.9	1057.9	1015.8

Time to Peak Velocity

	5 years			7 years			9 years		
	s	m	l	s	m	l	s	m	l
Control	378.6	336.5	324.4	307.1	297.9	288.2	347.9	321.4	344.3
Experimental	338.4	331.1	321.7	288.5	284.6	308.5	335.9	332.2	334.9

Time after Peak Velocity

	5 years			7 years			9 years		
	s	m	l	s	m	l	s	m	l
Control	741.4	690.9	611.1	708.1	606.5	519.3	813.9	740.5	646.8
Experimental	753.3	666.2	652.3	650.1	597.5	579.4	808.9	725.5	680.9

Constant Error

	5 years			7 years			9 years		
	s	m	l	s	m	l	s	m	l
Control	-1.52	-1.0	-2.0	0.29	0.16	0.65	-0.59	-0.06	-1.49
Experimental	-1.22	-0.43	-1.06	1.35	1.40	1.20	-0.78	0.07	-1.05

Absolute Constant Error

	5 years			7 years			9 years		
	s	m	l	s	m	l	s	m	l
Control	4.18	4.17	5.96	3.19	2.94	5.70	2.60	2.87	4.56
Experimental	3.80	3.98	5.02	3.87	4.11	4.60	3.35	2.65	3.41

Deviations prior to Peak Velocity

	5 years			7 years			9 years		
	s	m	l	s	m	l	s	m	l
Control	0.56	0.60	0.62	0.48	0.40	0.36	0.53	0.57	0.61
Experimental	0.56	0.60	0.57	0.37	0.32	0.41	0.73	0.68	0.67

Deviations post Peak Velocity

	5 years			7 years			9 years		
	s	m	l	s	m	l	s	m	l
Control	1.31	1.16	1.11	0.95	0.85	0.70	1.43	1.23	1.25
Experimental	1.16	1.08	1.19	0.82	0.87	0.96	1.53	1.38	1.26

Percentage of corrections pre-peak velocity in control condition.

	5 years			7 years			9 years		
	s	m	l	s	m	l	s	m	l
0 corrections	56.0	56.4	53.8	67.1	71.8	66.2	56.3	55.2	53.1
1 correction	33.0	30.7	33.8	20.0	17.4	22.3	35.4	33.0	32.5
2 corrections	9.8	9.6	10.7	11.5	10.8	4.8	7.0	11.9	14.4
3 corrections	1.2	3.3	1.0	1.3	0.0	0.0	0.7	0.0	0.0
4 corrections	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
> 4 corrections	0.0	0.0	0.7	0.0	0.0	0.0	0.7	0.0	0.0

Percentage of corrections pre-peak velocity in experimental condition

	5 years			7 years			9 years		
	s	m	l	s	m	l	s	m	l
0 corrections	61.7	54.9	54.8	71.5	74.4	67.3	54.7	52.2	51.6
1 correction	24.0	31.2	31.3	20.8	20.2	24.5	29.1	31.0	32.7
2 corrections	11.1	12.7	11.8	7.7	4.6	8.3	13.8	13.6	13.3
3 corrections	02.7	1.1	2.1	0.0	0.8	0.0	1.4	3.2	2.5
4 corrections	0.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
> 4 corrections	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0

Percentage of corrections post-peak velocity in control condition

	5 years			7 years			9 years		
	s	m	l	s	m	l	s	m	l
0 corrections	19.6	24.2	29.9	38.8	47.7	43.4	27.9	24.3	27.0
1 correction	45.6	42.0	38.9	34.7	30.4	38.1	29.7	38.6	39.9
2 corrections	22.2	27.0	22.9	19.7	13.7	11.9	23.6	28.6	20.8
3 corrections	9.2	5.8	7.7	6.8	6.3	0.0	13.9	7.9	7.9
4 corrections	3.4	1.1	0.7	0.0	1.3	0.0	4.1	0.0	1.8
> 4 corrections	0.0	0.0	0.0	0.0	0.7	0.0	0.7	0.6	2.5

Frequency of corrections post-peak velocity in experimental condition

	5 years			7 years			9 years		
	s	m	l	s	m	l	s	m	l
0 corrections	26.7	29.5	26.9	44.4	43.4	34.6	23.2	23.5	27.8
1 correction	40.4	42.3	40.3	36.4	35.7	41.4	35.8	36.5	34.3
2 corrections	25.1	20.3	20.7	14.2	14.5	19.7	21.0	26.0	26.6
3 corrections	5.5	6.7	10.9	3.1	4.9	3.1	15.5	9.0	8.1
4 corrections	1.1	1.1	1.1	1.4	0.9	0.6	1.7	2.9	2.7
> 4 corrections	1.1	0.1	0.0	0.6	0.5	0.6	2.9	2.1	0.6

Appendix F

Summary of Effects Tables

Summary of all Effects; design: (jan20mt.sta)
1-SS, 2-COND, 3-TARGET

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	2	661098.5	42	131821.7	5.015095	0.01114
2	1	1101.775	42	6419.988	0.171616	0.680787
3	2	477961.4	84	7066.311	67.63946	3.15E-18
12	2	375.4498	42	6419.988	0.058481	0.943272
13	4	1246.384	84	7066.311	0.176384	0.949978
23	2	49414.02	84	6319.665	7.819088	0.000769
123	4	7004.062	84	6319.665	1.108296	0.35811

Time to Peak Velocity

Summary of all Effects; design: (jan20ttpv.sta)
1-SS, 2-COND, 3-TARGET

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	2	51754.64	42	20888.98	2.477605	0.096134
2	1	4163.743	42	1558.342	2.671906	0.109608
3	2	6040.965	84	1499.925	4.027512	0.021367
12	2	1153.273	42	1558.342	0.740064	0.483201
13	4	3159.158	84	1499.925	2.106211	0.087179
23	2	4366.067	84	1277.027	3.41893	0.03737
123	4	1722.991	84	1277.027	1.34922	0.25861

Time after Peak Velocity

Summary of all Effects; design: (jan20tapv.sta)
1-SS, 2-COND, 3-TARGET

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	2	361660.7	42	66686.62	5.423288	0.008033
2	1	1047.266	42	6848.136	0.152927	0.69773
3	2	388799.6	84	6269.522	62.01423	2.87E-17
12	2	785.9017	42	6848.136	0.114761	0.891857
13	4	2073.402	84	6269.522	0.330711	0.856599
23	2	28637.51	84	5068.948	5.649597	0.004989
123	4	5505.506	84	5068.948	1.086124	0.368707

Peak Velocity

Summary of all Effects; design: (jan20pv.sta)
1-SS, 2-COND, 3-TARGET

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	2	209415.6	42	35015.99	5.980571	0.005182
2	1	507.0485	42	1107.084	0.458004	0.502269
3	2	8783.798	84	968.5878	9.068665	0.000272
12	2	1940.143	42	1107.084	1.752481	0.185781
13	4	1997.826	84	968.5878	2.062618	0.092965
23	2	5535.901	84	1000.429	5.533525	0.005527
123	4	2835.553	84	1000.429	2.834336	0.029406

Constant Error

Summary of all Effects; design: (jan20constant.sta)
1-SS, 2-COND, 3-TARGET

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	2	100.657	42	13.72759	7.332457	0.001856
2	1	21.03909	42	4.388669	4.793955	0.034167
3	2	9.731444	84	4.431421	2.19601	0.117593
12	2	3.796925	42	4.388669	0.865165	0.428348
13	4	4.079484	84	4.431421	0.920582	0.45597
23	2	0.469488	84	3.615238	0.129864	0.878391
123	4	0.967177	84	3.615238	0.267528	0.898073

Absolute Constant Error

Summary of all Effects; design: (jan20absconstant.sta)
1-SS, 2-COND, 3-TARGET

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	2	35.57204	42	6.262663	5.680017	0.006557
2	1	1.057257	42	2.289883	0.461708	0.500555
3	2	57.24445	84	2.575072	22.23024	1.78E-08
12	2	3.247759	42	2.289883	1.418308	0.253481
13	4	1.215798	84	2.575072	0.472141	0.756035
23	2	14.85178	84	2.33173	6.369424	0.002658
123	4	2.724117	84	2.33173	1.168281	0.330699

Deviations prior to peak velocity

Summary of all Effects; design: (devpredec.sta)
1-SS, 2-COND, 3-TARGET

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	2	1.475964	42	0.749686	1.968775	0.152304
2	1	0.026733	42	0.060664	0.440677	0.510424
3	2	0.0055	84	0.036688	0.149898	0.861025
12	2	0.179755	42	0.060664	2.963134	0.062545
13	4	0.024279	84	0.036688	0.661757	0.620293
23	2	0.001553	84	0.050904	0.030511	0.969961
123	4	0.047287	84	0.050904	0.928955	0.451209

Deviations post peak velocity

Summary of all Effects; design: (15statsdevpostdec.sta)
1-SS, 2-COND, 3-TARGET

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	2	5.463758	42	1.011443	5.401944	0.008171
2	1	0.059315	42	0.123361	0.480828	0.491865
3	2	0.383424	84	0.114896	3.337124	0.040309
12	2	0.112	42	0.123361	0.90791	0.411136
13	4	0.074702	84	0.114896	0.650165	0.628339
23	2	0.176392	84	0.102544	1.720163	0.185283
123	4	0.132571	84	0.102544	1.292825	0.279442

VITA AUCTORIS

Sandra McKay was born in Perth, Ontario. She graduated from Perth and District Collegiate Institute in 1993. From there she went on to the University of Windsor where she obtained a B.H.K. in Movement Science in 1997. She is currently a candidate for the Master's Degree in Human Kinetics at the University of Windsor and hopes to graduate in Spring 2000.